TRANSACTIONS
American Society for Steel Treating

VOL. IX MAY, 1926 No. 5

The object of the Society shall be to promote the arts and sciences connected with either the manufacture or treatment of metals, or both.—Constitution A. S. S. T., Art. II.

MRS. HENRY MARION HOWE

IT is with deep regret we announce the death of Mrs. Henry Marion Howe, wife of our late distinguished Honorary Member.

Mrs. Howe was born in Troy, N. Y., and was married to Dr. Howe on April 9, 1874. She occupied an enviable position among the leading women of the World. Because of her true devotion to Dr. Howe, her great interest in his scientific work, and her sincere appreciation of her responsibilities as a real helpmate, she was endeared to all who were fortunate enough to have her acquaintance. Her life activities have constantly been held up as a shining example of womanhood as to how they might best serve the scientific interests of their husbands.

Since Dr. Howe's death in 1922, Mrs. Howe has lived on their beautiful estate at Bedford Hills, N. Y., during the summers, spending the winters at Nassau, Bahama Islands.

Mrs. Howe's death occurred there on March 26, 1926. The funeral services were held in the quaint little colonial church at Bedford Hills on April 2, 1926. The funeral party went by motor to Stamford, Connecticut, where a special car awaited to complete the trip to Boston. Interment was at Cambridge beside the body of her distinguished husband.

Mrs. Howe was greatly interested in the American Society for Steel Treating, Dr. Howe having been one of the first Honorary Members. Upon the death of Dr. Howe the Society received permission from Mrs. Howe to establish the Henry Marion Howe Medal as a lasting memorial to her husband. Mrs. Howe exhibited remarkable interest in the design and preparation of the medal and was present at the annual convention at Pittsburgh where she received from the hands of President T. D. Lynch, a bronze replica of the medal at the same time the first medal was presented to Emanuel J. Janitzky. She was again present at the last

convention held in Cleveland and Dr. H. H. Lester, the medalist for 1925, had the honor of receiving the medal from Mrs. Howe.

Mrs. Howe has been a source of inspiration to many. Her loss will be greatly felt. She will be missed.

HARTFORD AND THE SPRING SECTIONAL MEETING

THE Hartford Chapter extends a most cordial invitation to all members of the Society to attend the Spring Sectional Meeting on May 20 and 21, 1926. The technical sessions will be of interest to metallurgist and practical man alike; the plant inspection trips take you into those typical industries for which New England in general and Hartford in particular is famous; several entertainment features have been provided to insure enjoyment for all attending, including the ladies. If you miss this meeting you will miss the best sectional meeting the Society has ever held.

INTERESTING FACTS ABOUT HARTFORD

IN 1636, sixteen years after the Pilgrims landed at Plymouth, a small group of people left Massachusetts under the leadership of Rev. Thomas Hooker and went to a Dutch trading post located on the Connecticut River which they called Hartford. Despite the ferocity and frequent attacks of the Indians, the colony prospered and these early pioneers contributed much to the welfare of New England.

In Colonial days Connecticut was a great agricultural state—the granary of New England. But the discovery of metal in the soil and its early use in making nails, etc. in the home, and later in shops, was the cause of the people more and more abandoning farming for the workshops. This resulted in the growth and development of cities where workshops were located. Hartford, being advantageously situated, and one of the oldest cities in Connecticut, rapidly developed into a leading manufacturing center in the metal working trades and is today one of the noted industrial cities in the United States. Its industrial history is an interesting one. Diversified in the extreme, its products range from the tiniest watch screw to the tremendous gate valves used in harnessing Niagara Falls. These products of fine quality and excellent workmanship go to all parts of the world.

Hartford's progress is also largely due to the civic pride of

its citizens. They embody the ideal in the real. Situated midway between New York and Boston in the heart of New England, the city became an educational and art center. Many educational and recreational facilities are available to the people. From kindergarten through Trinity College excellent teachers prepare the youth for a useful and happy life. The earliest attempts to instruct the deaf and dumb were made here in Hartford. Extensive public, historical and reference libraries, and many art galleries and museums afford added facilities to the student.

Wadsworth Atheneum, the Morgan Memorial, and the Colt Memorial are now under the management of the same board of trustees and contain much of historical interest. They are located at Main and Atheneum Streets. The Morgan Memorial erected by the late J. Pierpont Morgan, a native of Hartford, in memory of his father, contains a matchless set of tapestries said to be the finest in America; his splendid collection of Meissen and Dresden porcelains and other art works; also the magnificently illustrated catalog of his art treasures; his set of Gould's Birds; Curtis' North American Indians; and other rare and valuable art treasures. The Atheneum contains a gallery of fine pictures, pottery, silver-ware, bric-a-brac, etc. The Colt Memorial is small, but very fine. Here may be seen the origin and development of the revolver and other firearms and various art treasures of great interest.

The Connecticut Historical Society has among other things an interesting collection of Colonial and Indian relics.

In the Watkinson Library may be seen J. C. Hill's fine collection of medals and badges and his library of literature concerning them.

Another place of interest is the State Arsenal and Armory which is one of the finest in the United States. It is built of Mohegan granite and covers about two acres. The drill room accommodates 12,000 people. It is located in the extreme western part of Bushnell Park across the Park River near Broad Street.

The name of Hartford has been linked with Charter Oak for over 200 years. This venerable old tree was a landmark and peace tree of the Indians. By the size of its leaves they fixed the time for the planting of corn and under its shade they held their conferences. But it will best be remembered as the hiding place of the Connecticut charter when Captain Joseph Wadsworth so clev-

erly outwitted the dapper Sir Edmund Andros who had come to take possession of it. The Charter Oak fell in a storm in 1856 and a marble tablet in a brick wall on Charter Oak Avenue marks its former site.

Wadsworth Inn, at Albany and Prospect Avenues, the western boundary of the city, has been the home of the famous Wadsworth family since 1820 and is of interest to the traveler because here lived Joseph Wadsworth's descendants, the hero, who, on that memorial evening in 1687, hastily extinguished the light, seized the charter and hid it in the old oak, thus retaining the written grant of the king for the colony to choose its own government. Wadsworth kept the colony of Connecticut safe for democracy. Sir Andros graciously acknowledged his defeat.

Hartford is one of the most attractive cities in this country. It is well-laid out and compactly built on rolling ground and from its elevated sections splendid views of the picturesque valley of the "river with the long tide" delight the observer. The Connecticut valley is in many places twenty miles across.

Main Street is the principal business street and here are located many retail shops. Prospect Avenue is but one of the fine residential streets.

Many insurance companies have their headquarters here and investments in these companies are said to total about one billion dollars. The homes of these companies are fine modern buildings and several of them have established extensive recreational facilities for their employees and one of the largest companies has a splendid country club where the families of the employees go for tennis, baseball and other sports. These companies have come to know the great advantage of team work in business and play. Indeed, all Hartford breathes a spirit of hospitality.

Students of landscape gardening and fresh air and playground problems come to Hartford to study its park and playground systems. It has one of the most splendid park systems in America, embracing about 1500 acres. Bushnell Park containing some 47 acres is located in the center of the city adjoining the capitol grounds. As the traveler crosses the bridge here over the Park River, he comes upon the Soldiers' Memorial Arch, a splendid gateway into Bushnell Park, and just beyond stands the State Capitol, an imposing building of white marble, said to be the second finest, if not in many respects the finest, state capitol

building in this country. Here may be seen portraits and statues of famous men in history. It is said to be the only large public building in America built within the appropriation. Keney Park to the north is the largest park and contains about 665 acres. Goodwin Park is to the extreme south and Elizabeth Park is in the western part of the city. The latter is noted for its flowers and trees, and especially for its fine rose garden. The fair grounds and race track are located in Charter Oak Park.

The Connecticut River flows through the city and is spanned by a superb granite bridge at Morgan Street which connects Hartford with East Hartford. This bridge was completed in 1907 and is said to be the largest mass of any purely stone bridge in the world. It is approximately 1192 feet long and 82 feet wide (London bridge is 42 feet wide). It consists of 9 spans and its total cost with improvements and boulevards was about $3,000,000. The great causeway approaching the bridge on the east adds greatly to its beauty and massiveness.

As a travel center Hartford is rapidly coming to be of great importance. Tourists seeking beauty spots traverse the highlands to the north and west and pass through fertile plains and orchards on the east. Many excellent roads bordered with fine old trees radiate from Hartford in every direction and afford picturesque motor drives.

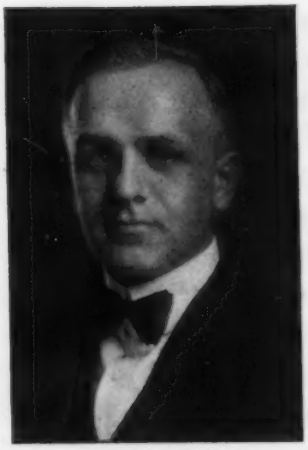
Hartford has always had citizens who were pioneers and many things had their beginning here. The first woolen mills were begun here; the first steam road wagon, the first revolver pistol containing several chambers which could be discharged through a single barrel, a machine for exact and uniform measurement within a limit of 1/50000 of an inch, etc., all were first made here.

The *Hartford Courant,* established in 1764, is said to be the oldest newspaper in the United States and was instrumental in creating and shaping public opinion in the years preceding the war of independence.

In the last issue of TRANSACTIONS a statement was made regarding the price of electricity in Hartford in which it was stated that Hartford had the lowest rates in the country. We find, however, that this is not a correct statement when applied to the rates for all types of loads. It was not, however, our purpose to discuss rates at all because such a discussion involves many variables. However, it is a fact that Hartford does have one of the lowest

A. J. PORTER, JR.

J. C. KIELMAN

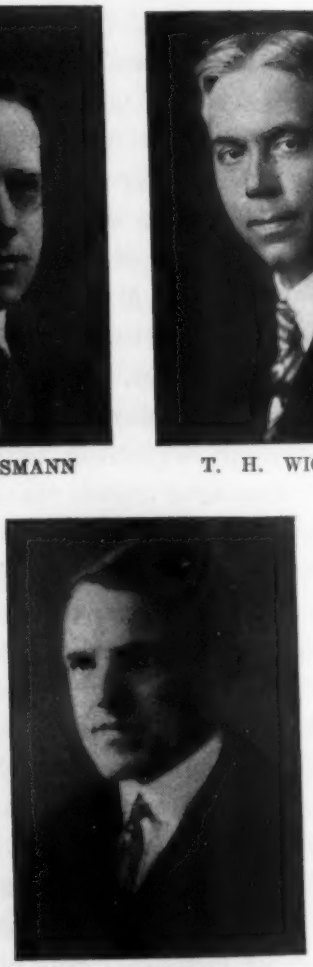


J. S. VANICK

M. A. GROSSMANN

T. H. WICKENDEN

N. L. MOCHEL



J. R. FREEMAN, JR.

AUTHORS OF PAPERS TO BE PRESENTED AT THE SPRING SECTIONAL MEETING, HARTFORD, CONNECTICUT, MAY 20 AND 21, 1926

rates for small consumers having loads up to 100 kilowatts of demand.

This coming together on May 20 and 21 of men from all parts of the country will be significant. From the very beginning of life, contacts in human affairs have resulted in advancement. They enrich life, deepen one's sympathies, widen his horizon, and add to his knowledge and experiences. Many new ideas will have their birth at this meeting here in the "cradle of democracy" to be carried north and south, east and west and you should not miss this opportunity to rub elbows with many others who are intensely interested in the science of metals.

A glimpse into the lives of some of the men who will contribute their ideas and the results of their experiments and observations is given.

J. R. Freeman, Jr.

J. R. Freeman, Jr., after his graduation from the department of electro-chemistry at the Massachusetts Institute of Technology in 1916, made a tour of the Far East with his father, Dr. Brashear, and Mr. Ambrose Swasey. Upon his return, he took service with the Bureau of Standards in the metallurgical department and is still with the Bureau. He was for six months exchange researcher in the British National Physical Laboratory at Teddington, working under Dr. Rosenhain. In 1923 he spent six months making a tour of metallurgical works in England, France, Germany and Northern Italy. He is at present traveling in China and India where he will visit the Tata Steel Works.

N. L. Mochel

N. L. Mochel began his career in 1912 in the Inspection Department of the Westinghouse Machine Company and continued in this position after the merger with the Westinghouse Electric and Manufacturing Company. In 1920 he was given the position of metallurgical engineer at the new South Philadelphia Works. He served with the Engineer Corps of the United States army in France. He was born, raised and educated in Pittsburgh.

T. H. Wickenden

T. H. Wickenden has been with the Development and Research Department of The International Nickel Company since 1922. After he graduated from the University of Michigan as Bachelor of Chemical Engineering he was connected with several automobile companies in a metallurgical and engineering capacity.

J. S. Vanick

J. S. Vanick has been connected with the Research and Development Department of the International Nickel Company, New York City, since December, 1923. After he received his degree of Master of Science at Georgetown University, he engaged in the inspection of engine materials in the Aero Inspection Department of the British Ministry of Munitions in the United States and later in a similar capacity with the Inspection Division Ordnance Department of the United States Army. He subsequently engaged in research metallurgy at the Bureau of Standards for Metallurgical Division, Technical Staff of the United States army. His birthplace is Cleveland.

A. J. Porter, Jr.

A. J. Porter, Jr., is sales manager of the Bridgeport office of the Heppenstall Forge Co., Bridgeport, Conn.

He was born in Philadelphia, in 1895, and was educated in public schools of Philadelphia and Bridgeport, Conn. Spent 2½ years at Penn State studying mechanical engineering.

He left Penn State in 1917 to enter U. S. Tank Corps and served with this organization in France.

Upon return from service in 1919 regularly entered the employ of the Heppenstall Forge Company.

He worked through the machine shop, the forge shop and heat treating department. Previous to entering sales end in 1921 had charge of Production.

J. C. Kielman

J. C. Kielman is engineer at forge plant New Departure Manufacturing Co., Bristol, Conn. Graduated from Lafayette College, Easton, Pa., in 1914 with a degree of M. E. Was born March 12, 1891 at Portsmouth, Ohio.

M. A. Grossmann

M. A. Grossmann was graduated from Massachusetts Institute of Technology, 1911, then associated in various capacities with the Pittsburgh Testing Laboratory, Vanadium Corporation of America, U. S. Bureau of Standards, Electric Alloy Steel Co., Atlas Steel Corporation, and, lately, research metallurgist, and then metallurgical engineer of the United Alloy Steel Corporation, Canton, Ohio.

PROGRAM FOR SPRING SECTIONAL MEETING, HOTEL BOND, HARTFORD, CONNECTICUT—MAY 20-21, 1926

WEDNESDAY, MAY 19

10:00 A. M.—Meeting of Board of Directors.

6:00 P. M.—Early Bird's Dinner and Registration—Hotel Bond.

THURSDAY, MAY 20

Ball Room, Hotel Bond

8:30-9:30 A. M.—Registration.

Morning Technical Session

F. P. Gilligan, Chairman.

9:30-10:30 A. M.—*Recrystallization Temperatures of Cold-Rolled Electrolytic Iron and Open-Hearth Steel Strip*—John R. Freeman Jr., Bureau of Standards, Washington, D. C.

10:30-11:30 A. M.—*Factors Affecting the Machinability of Alloy Steels*—J. S. Vanick and T. H. Wickenden International Nickel Co.

Afternoon Session

1:30- 4:30 P. M.—Plant Inspection at the plants of:

Billings and Spencer Company
Colt's Armory
Hartford Rubber Works
Royal Typewriter Company
Underwood Typewriter Company
Union Drawn Steel Company
Pratt and Whitney Company

Evening Session

6:30 P. M. Banquet, Ball Room, Hotel Bond.

FRIDAY, MAY 21

Ball Room, Hotel Bond.

Morning Technical Session

A. H. d'Arcambal, Chairman.

9:30-10:30 A. M.—*Necessary Precautions in The Manufacture of Alloy Steels*—Marcus A. Grossmann—United Alloy Steel Company, Canton, Ohio.

10:30-11:30 A. M.—*Forging by the Upset Process*—J. C. Kielman, New Departure Manufacturing Company, Bristol, Connecticut.

Afternoon Session

1:30- 5:00 P. M.—Plant Inspection at the plants of:

New Departure Manufacturing Company, Bristol Conn.
International Silver Co., Meriden, Conn.

Evening Technical Session

S. P. Rockwell, Chairman.

7:00- 8:00 P. M.—"*Stainless Iron*"—Norman L. Mochel, Westinghouse Electric and Manufacturing Company, Philadelphia.

8:00 P. M. *Heat Treatment of Die Blocks*—Alfred J. Porter, Jr.,—Heppenstall Forge Company, Bridgeport, Conn.

SATURDAY, MAY 22

9:00-11:00 A. M.—Special Plant Inspection Trips as Requested by Members.

Hotel Reservations

The Hotel Bond will be the official headquarters for the Spring Sectional Meeting of the society to be held in Hartford. All technical sessions will be held at the Bond. Members and guests are requested to make their reservations directly with the hotel management, stating the price and the type of accommodation desired and requesting an acknowledgment of the reservation.

Rates for several of the hotels in Hartford follow:—

Hotel Bond	$3.50 to $5.00
Hotel Bond Annex	$3.00 to $5.00
Heublein Hotel	$3.50 to $4.00
Garde Hotel	$3.00 to $3.50
Highland Court Hotel	$3.00

THE NEW FORT WAYNE GROUP

THE first charter for a new group of the A. S. S. T. since the admission of San Francisco, some two and one-half years ago, was issued to the important industrial city of Fort Wayne, Indiana, at a preliminary organization meeting, held on March 13, at the Keenan Hotel.

The following officers were elected pro tem: chairman, G. E. Tibbits, is factory manager, S. F. Bowser Co.; vice-chairman, E. H. Sohner, is assistant superintendent, International Harvester Co.; secretary-treasurer, A. L. Cramp, a past-chairman of the Indianapolis Chapter, is at present machine foreman of International Harvester Co. The following were elected as members of the executive committee: Charles Grimes, heat treating foreman, and F. A. Newman, heat treater of the General Electric Co,; J. Hentzler, tool room foreman, and C. Frauenfelder, Tokheim Oil, Pump and Tank Co.; W. P. Burt, factory superintendent, and George Friess, tool room foreman of the Wayne Tank and Pump Co., and J. A. Hanson, chief tool designer, and M. E. Langdon, foundry general foreman of the S. F. Bowser Co.

The first regular meeting of the new group was held in the Assembly Hall of the Y. M. C. A., on Thursday evening, April 1, 1926. Due to the illness of chairman Tibbits, the meeting was conducted by vice-chairman Sohner. There was an attendance of over 100 to witness the moving picture, entitled, "The Manufacture of Alloy Steel," presented by S. A. Richardson, research metal-

lurgist of the Interstate Iron and Steel Company. Mr. Richardson prefaced the moving picture with a practical talk on the various methods of the manufacture of steel, explaining in detail what constituted the various grades, as well as the effect of different alloying elements. There was an extended discussion at the close of Mr. Richardson's talk, and this first meeting of the group was voted a decided success.

The second meeting of this group will be held the latter part of April and will be addressed by Prof. John A. Keller of Purdue University.

A NEW GROUP AT MONTREAL

OVER 40 individuals, representing 28 metal working firms, petitioned the Board of the A. S. S. T. for a charter for a Montreal group. The secretary attended the organization meeting on April 7, held at the Mt. Royal Hotel. After a thorough discussion of the prospects of a group, it was the consensus of opinion that Montreal should have at least 100 to 150 members.

It was decided to elect temporary officers, and the following organization was perfected: chairman, Dr. Alfred Stansfield, Associate of the Royal School of Mines, Fellow of the Royal Society of Canada and Birks Professor of Metallurgy, McGill University, and the author of the "Electric Furnace for Iron and Steel"; vice-chairman, C. F. Pascoe, metallurgist, Canadian Car and Foundry Co., and Canadian Steel Foundries; secretary-treasurer, Fred H. Williams, assistant engineer of tests, Canadian National Railway. The following were elected members of the Executive Committee: Robert Job, vice-president, Milton-Hershey Co.; C. D. Slimpin, industrial engineer, Montreal Light, Heat and Power Co.; W. W. Townsend, tool supervisor, Montreal Locomotive Works; Robt. J. Noaks, superintendent, Canadian Pneumatic Tool Co.; H. S. Weldon, metallurgist, Canadian Inspection and Testing Co.; Gordon Sproule, assistant professor of metallurgy, McGill University; and W. J. Hall, Production Materials, Ltd.

The executive committee held a meeting on April 15, at which plans and arrangements were made for the first regular meeting of the new group. Montreal is a live, wide-awake industrial center, and the enthusiasm displayed for the new group indicates another successful unit of the A. S. S. T.

UNAUDITED PROFIT AND LOSS STATEMENT AMERICAN SOCIETY *for* STEEL TREATING

For the period from January 1 to March 31, 1926

INCOME		
Gross Dues		$14,615.10
Transactions Advertising		9,085.50
Transactions Sales		220.60
Transactions Subscriptions		353.17
Reprints		154.65
Bindery Account		284.00
Book Account		348.34
Pencil Account		19.50
Pins and Buttons		8.00
Miscellaneous Receipts		79.00
Data Sheets		613.36
Discounts Received		141.78
Interest		56.86
Sustaining Exhibit Membership		4,250.00
TOTAL INCOME		$30,229.86
EXPENSE		
Local Chapters	$ 6,720.19	
Buffalo Sectional Meeting	333.86	
Transactions	8,581.46	
Reprints	92.53	
Bindery Account	428.29	
Book Account	197.98	
Library	49.19	
Data Sheets	1,301.77	
Discounts Allowed	108.52	
Bank Exchange	.79	
General Expense	1,772.03	
Secretary's Office	2,221.07	
President's Office	970.13	
Treasurer's Office	1,068.74	
Director's Expenses	839.61	
National Committees	1,449.30	
Old Accounts Cancelled which were originally set up in error	105.00	
TOTAL EXPENSE		$26,240.46
EXCESS OF INCOME OVER EXPENSE		3,989.40

BALANCE SHEET

As of March 31, 1926

ASSETS			
Commercial Account—Cleveland Trust Co			$16,056.09
Savings Accounts			28,906.03
Accounts Receivable			4,811.77
Accrued Interest			342.57
Investments—U. S. Treasury Certificates	$ 2,235.00		
Water Bonds—Euclid Village	3,000.00		
Liberty Bonds	28,000.00		
Cleveland Trust 5½% Collateral Trust Bonds	15,000.00		48,235.00
Office Furniture and Fixtures			692.50
Inventory			2,452.65
1926 Convention Prepaid Expenses			3,481.02
1927 Convention Prepaid Expenses			276.20
TOTAL ASSETS			$105,253.83
LIABILITIES, RESERVES AND SURPLUS			
Accounts Payable			2,123.28
1926 Convention Advance Receipts			12,751.50
Reserves for:			
Past Due and Doubtful Accounts			912.75
Dues Paid in Advance			10,000.00
Permanent Convention Reserve			20,000.00
H. M. Howe Fund			5,000.00
Surplus—January 1. 1926	52,476.90		
Less—Increase to Henry Marion Howe Medal Fund Reserve	2,000.00		
	$50,476.90		
Plus—Excess Income for period from January 1 to March 31, 1926, per Profit and Loss statement as above	3,989.40		
Present Surplus			$54,466.30
TOTAL LIABILITIES, RESERVES AND SURPLUS			$105,253.83

EFFECT OF REHEATING ON COLD DRAWN BARS

By S. C. Spalding

Abstract

This paper deals with three steels, a carbon-manganese, a 3.50 per cent nickel and a chromium-vanadium, all 0.20 to 0.30 per cent carbon.

Hot-rolled bars of each were drawn in one draft from three different sizes to one finished size, thus effecting three different amounts of cold work.

The material was tested in tension, impact, hardness and electrical conductivity, in the hot-rolled, cold drawn, cold drawn and reheated, and quenched and reheated condition both before and after cold drawing.

Tests show effects of reheating cold drawn steel, also the effect of heat treating before or after cold drawing.

The general conclusions are as follows:

1. The yield points for the manganese, 3.50 per cent nickel and the chromium-vanadium steels are considerably increased after cold drawing and reheating to 600 degrees Fahr. (315 degrees Cent.). The tensile strength is only slightly increased. There is a slight loss in the ductility and notched-bar toughness.

2. At 1000 and 1200 degrees Fahr. (540 and 595 degrees Cent.) the yield point and tensile strength are reduced to their initial figure, while the ductility and notched-bar figures have made considerable gain over their initial values.

3. Reheating over 1200 degrees Fahr. (595 degrees Cent.) causes the yield point and tensile strength to fall rapidly and the ductility and notched-bar figures to increase.

4. The chromium-vanadium steels require a higher reheating temperature to restore their normal physical condition (a proper balance between the tensile strength and ductility).

IN making a survey of the investigational work done on the cold drawing of steel followed by annealing, we find comparatively few papers dealing with this subject. The majority of those which are available are of a non-technical nature and pertain mainly to commercial practices and processes in wire making.

A paper presented before the Cleveland Convention of the Society, September, 1925. The author, S. C. Spalding, member of the Syracuse Chapter of the Society, is metallurgist with the Halcomb Steel Co., Syracuse, N. Y.

Brief abstracts of some of the more important papers on the subject are herewith presented.[1]

Brunton[2] deals with the practical problems of drawing and especially of pickling. He also shows the effects of annealing above the critical temperature on rod and wire as affecting the final desired result.

Longmuir[3] differentiates between annealings above the critical range and low temperature annealings. He says, "A sharp line must be drawn between first and later annealings. The first annealing should relate solely to the condition of the hot-rolled rod, while later annealings have a relation to the stresses developed by cold working. By suitable adjustment of annealing temperatures to cold work, a given hardness can be obtained to a certain extent irrespective of the composition of the steel." He lays great stress on the necessity of putting the rod in a uniform condition by the first annealing, in order to produce uniform wire. He deals with steels ranging from 0.10 to 1.04 per cent carbon and gives the effect of initial and subsequent annealings, size, number, and amount of draft on the final wire in regard to the tensile properties. In the second paper, he deals with the effects of increasing amounts of draft on the tensile properties for carbon steels. He also investigates the effect of segregation on the drawing of wire.

Tinsley[4] deals with the commercial processes in making and handling wire, as well as its subsequent hardening and tempering. In regard to annealing he says, "Few of our authorities, however, seem to recognize the fact that in the most common of all annealing of steel wire, that to remove the effects of cold working it is not necessary to reach the critical temperature. A temperature of 1100 deegrees Fahr. (2010 degrees Cent.) is entirely sufficient to relieve the strained condition of the grain. Process annealing practically brings the rod or wire, regardless of size, back to its original condition with regard to tensile

[1]J. P. Bedson, "Iron and Steel Wire and the Development of Its Manufacture," *Journal*, Iron and Steel Institute, 1893, No. II.

[2]J. D. Brunton, "Wire and Wire Drawing," *Journal*, West Scotland Iron and Steel Institute, 1900. "The Heat Treatment of Wire," *Journal*, Iron and Steel Institute, 1906, No. II.

[3]Percy Longmuir, "Some Aspects of Wire Drawing," *Journal*, Iron and Steel Institute, 1912, No. II, Vol. 86, page 188. "Studies in the Cold Flow of Steel," *Journal*, Iron and Steel Institute, 1913, No. I, Vol. 87, page 93.

[4]J. F. Tinsley, "The Practical Importance of Heat Treatment in the Steel and Wire Industry," American Iron and Steel Institute, 1914.

strength and ductility. For dead soft wire we must go above the critical range. This entirely obliterates any cold work effect. The low temperature annealings cause a breaking up and rearrangement of structure, but not a complete obliteration of the cold-worked structure. In annealing of low carbon steel wire, the rate of cooling from the annealing temperature is of little consequence as affecting structure."

Goerens[5] made an exhaustive research on the effect of different amounts of cold work and different annealing temperatures on: tensile properties, hardness, specific gravity, electrical resistance, magnetic properties, solution potential, rate of solution in acids, and microstructures. The steels he investigated ranged from 0.11 to 0.78 per cent carbon. He found that increasing the cold work caused proportional increases in the tensile strength and hardness, with decreased ductility. The increase is greater in the low carbon steels. In this connection he says, "The effect of carbon may, hence, be defined as causing an increase in the elastic limit and limit of proportionality, which may reach 90 kilograms per square millimeter as long as the amount of carbon does not exceed 0.6 per cent. At this maximum value the reduction of area is less in proportion as the carbon is higher. When this proportion approaches the eutectic point, 0.90 per cent carbon, free ferrite disappears and the ductility is so far reduced that a wire, even when drawn to near the breaking point, only attains a limit of proportionality and an elastic limit half as great as that reached by the low carbon material. This behavior shows that the selection of very high carbon steels is not advisable when high elastic limit is particularly desirable."

With regard to conductivity, the results are not reliable and the only conclusion that can be drawn from them is that by cold drawing, the electrical resistance of pure iron is distinctly decreased, whereas in the case of medium and hard steels it is uncertain whether any change is produced by such treatment.

With reference to the effect of reheating after cold work, he says, "The tensile strength is even affected by heating at about 212 degrees Fahr. (100 degrees Cent.) to a marked degree. It sinks slowly with increasing temperature. In the neigh-

[5]Goerens, "The Influence of Cold Working and Annealing on the Properties of Iron and Steel," Iron and Steel Institute, Carnegie Scholarship, *Memoirs*, Vol. 3, 1911.

borhood of 970 degrees Fahr. (520 degrees Cent.) it makes a sudden change, falling from 66 kilograms per square millimeter to 45 kilograms per square millimeter, touching 40 kilograms per square millimeter at 1112 degrees Fahr. (600 degrees Cent.)."

The elongation exhibits a corresponding behavior. It increases only slightly from 6.7 to 10.7 per cent up to 970 degrees Fahr., but rushes suddenly up to double that amount at that temperature. With the reduction of area it is similar.

The present investigations allow a closer delimitation to be given to the conceptions of cold and hot working. It is known that if the rolling is finished at too low a temperature brittleness is likely to result in certain materials. The temperature limits for cold rolling are not yet determined. The present experiments indicate that 970 degrees Fahr. (520 degrees Cent.) can be well regarded as the boundary between the cold and hot working ranges for soft steel. The duration experiments show that even after many hours' annealing at temperatures between 925 and 930 degrees Fahr. (495 and 500 degrees Cent.), the changes that have been produced by cold working are only in part eliminated, but by heating only a short time to 970 degrees Fahr. the effects of the cold working are dispelled, leaving only mere traces.

The difference between cold and hot working is, that part of the metal is converted into a hardened condition by the former operation. According to Beilby's assumption, the length to which the deformation can be continued reaches a limit when such a large part of the metal has been converted into the hardened condition that it preponderates and thus thrusts its properties into the foreground, while those of the soft metal cease to be of account. The hardened state of the metal produced is less stable than the normal soft state, as is indicated by the increased solution potential. The metal is constantly endeavoring to revert to the stable state. Above 970 degrees Fahr. (520 degrees Cent.), the rapidity of this reversion to equilibrium is sufficiently great so that as a general rule the equilibrium is not disturbed during the working operation. Below this temperature the transition of the hardened into the softened condition progresses slowly and makes only slight progress even after hours and days of heating. For this reason the deformation and the development of the hardened form of iron, takes place more rapidly than the reversion to the stable soft state, and when the deformation has reached

a certain magnitude, the properties of the metal have changed to such an extent that a further change cannot be achieved unless the soft condition is restored by raising the temperature to above 970 degrees Fahr. (520 degrees Cent.).

A further deduction may be drawn in reference to the annealing temperature that is necessary for the annealing of cold-worked material. The temperature of the allotropic changes need not be reached for the establishment of the equilibrium and the dispersion of the cold hardened condition. Heating for a short time at 970 degrees Fahr., or to 1075 degrees Fahr., according to the kind of material, suffices to restore almost completely the normal properties of the materials.

Industrially, annealing at the lowest possible temperature should be an advantage resulting in low fuel consumption and a product free from scale and decarburization.

In his conclusions the duration experiment shows that even after many hours of annealing at temperatures between 925 and 930 degrees Fahr., the changes that have been produced by cold working are only in part reversed, while by a short heating at 970 degrees Fahr., the effects of cold working are dispelled, leaving mere traces.

The influence of the annealing temperature asserts itself even when heating at lower temperatures than 970 degrees Fahr. by removing the effects of cold working. At 970 degrees Fahr., a fairly sudden reversion of the metal to its original state ensues. The temperature at which the sudden change occurs is different for different kinds of mild steel, and varies between the limits of 970 and 1075 degrees Fahr.

The influence of the duration of the annealing is best expressed by stating that the action characteristic for any given temperature is exerted within the first few minutes and prolonged heating produces only small changes in the respective properties.

Object of Paper

The present investigation was conducted to determine the effect of reheating at low temperatures cold drawn alloy steel bars. The steels selected were nickel, chromium-vanadium and manganese. Each steel was made in three sizes of rods—$\frac{13}{32}$-inch diameter, $\frac{11}{32}$-inch diameter and $\frac{1}{2}$-inch diameter. These rods

were drawn to 0.450-inch diameter in one pass. This gave reductions of 42.5 per cent, 28.1 per cent, and 18.9 per cent.

Table I

Chemical Compositions of Steels

	Size	C	Si	Mn	P	S	Cr	Ni	Va
Manganese Steel A	12/32	0.28	0.05	0.77	0.049	0.056	...	...	...
Manganese Steel B	17/32	0.32	0.19	1.44	0.068	0.062	...	...	...
Manganese Steel C	1/2	0.27	0.08	0.96	0.070	0.054	...	...	...
Nickel Steel A	12/32	0.25	0.23	0.60	0.015	0.011	...	3.37	...
Nickel Steel B	17/32	0.32	0.23	0.60	0.015	0.011	...	3.81	...
Nickel Steel C	1/2	0.25	0.23	0.60	0.015	0.011	...	3.41	...
Chromium-Vanadium Steel A	12/32	0.27	0.37	0.75	0.012	0.026	0.95	0.19	0.19
Chromium-Vanadium Steel B	17/32	0.27	0.37	0.75	0.012	0.026	0.98	...	0.16
Chromium-Vanadium Steel C	1/2	0.27	0.37	0.75	0.012	0.026	0.95	...	0.19

Table II

Brinell Hardness Numbers on Hot-Rolled Stock

	A—Steels	B—Steels	C—Steels
	Diameter of Rods in Inches		
	12/32	17/32	1/2
Manganese Steel	169	179	159
Nickel Steel	172	212	183
Chromium-Vanadium Steel	255	231	262

Test Specimens

Tensile test specimens were cut 14 inches long, allowing 3½ to 4 inches for gripping, leaving approximately 6 inches free pulling length. Punch marks were laid off every inch to determine the elongation (Figs. 1, 2 and 3). Brinell hardness tests (Fig. 4) were made on the unstressed ends of the tensile pieces. (Table II.)

Conductivity test bars were cut 19 inches long, the potential drop being measured over a 12-inch length. These tests were made on Leeds and Northrup apparatus (Kelvin Double Bridge), with test piece immersed in an oil bath which was kept at a constant temperature of 104 degrees Fahr. (Figs. 5, 6 and 7.)

Izod impact specimens were cut from the conductivity test bars. They were of the 3-notch type, 0.450-inch diameter, 45-degree notches, 0.13 inches deep. The tests were made on a 120-foot pound Izod machine. (Figs. 8 to 14.)

All reheating temperatures were held one-half hour and the specimens then quenched in water.

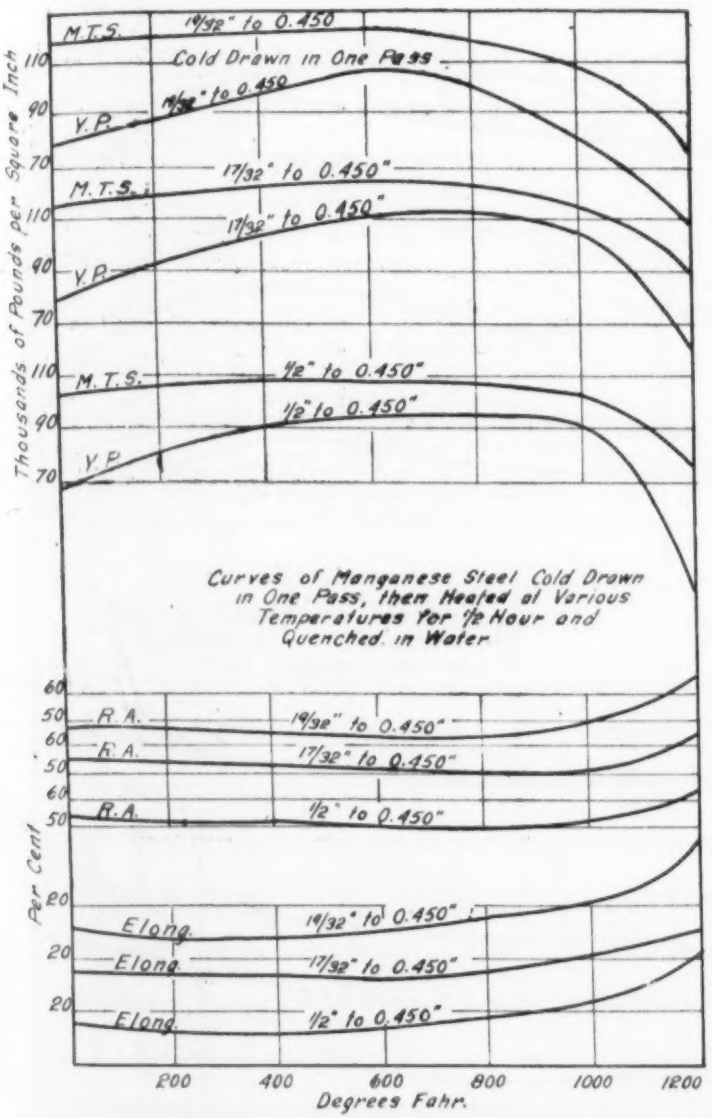


Fig. 1—Curves of Manganese Steel Cold Drawn in One Pass, Reheated at Various Temperatures for 30 Minutes and then Quenched in Water. The Curves Labelled MTS, YP, RA and Elong, refer to Maximum Tensile Strength, Yield Point, Reduction of Area and Elongation, respectively.

Tensile Strength and Brinell Hardness Data

The tensile strength data show the yield point and tensile strength to have increased, while there is only a slight decrease in the ductility with reheating temperatures up to 600 degrees

Fahr. Above this temperature the tensile strength and yield point fall off rapidly with a corresponding increase in elongation and reduction of area.

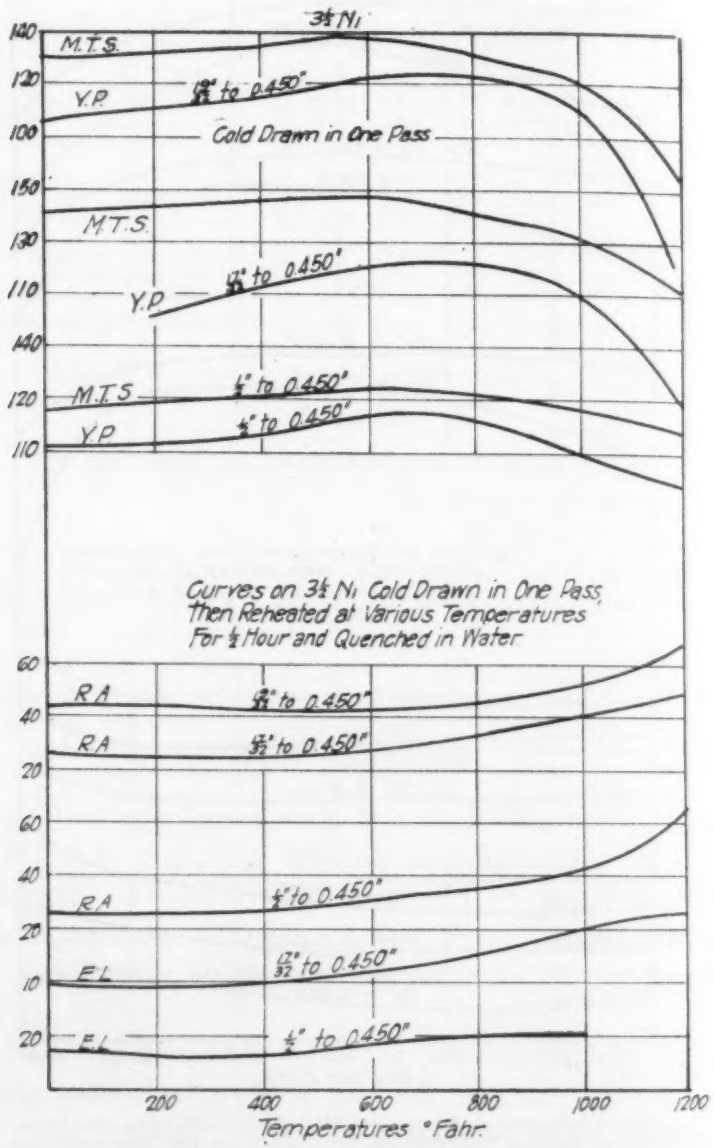


Fig. 2—Curves of 3½ Per Cent Nickel Steel Cold Drawn in One Pass, Reheated at Various Temperatures for 30 Minutes and then Quenched in Water. The Curves Labelled MTS, YP, RA and El. refer to Maximum Tensile Strength, Yield Point, Reduction of Area and Elongation, respectively.

Manganese Steel

Manganese steel A (see Table I) had a yield point of 28,000 pounds per square inch or an increase of 35 per cent, with no

decrease in elongation, but a 4 per cent decrease in reduction of area. The manganese steel B gave 32,000 pounds per square inch or 40 per cent increase in yield point, with one per cent decrease

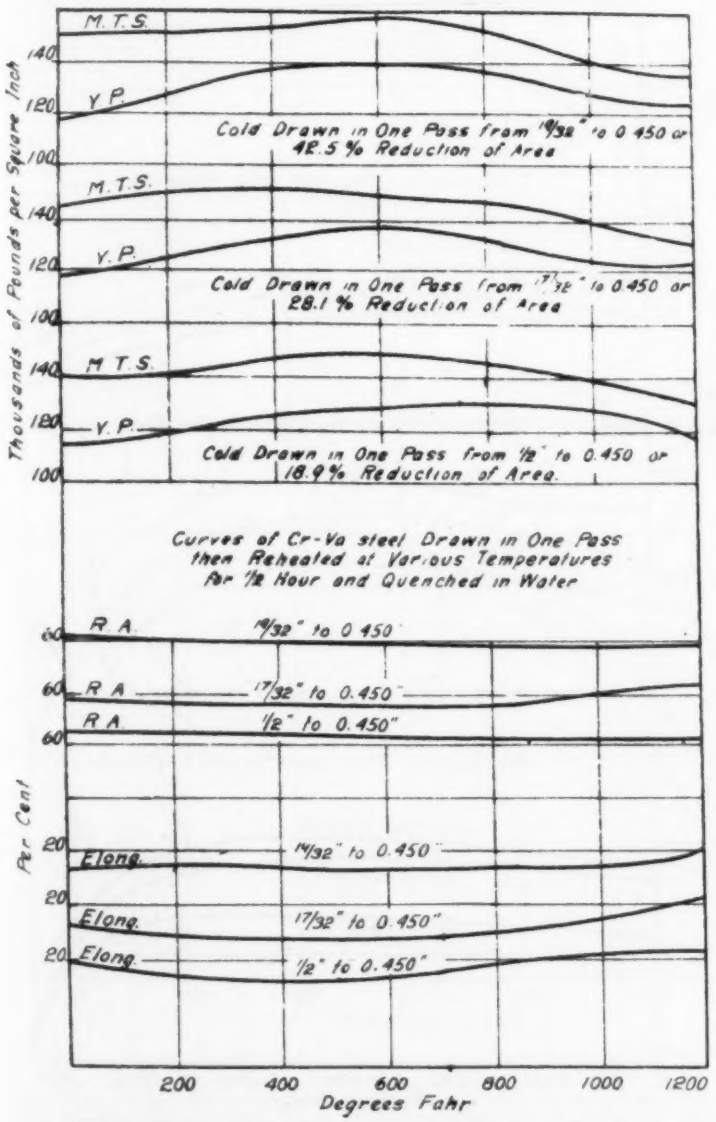

M.T.S.
Y.P.
Cold Drawn in One Pass from 19/32" to 0.450 or 42.5 % Reduction of Area
M.T.S.
Y.P.
Cold Drawn in One Pass from 17/32" to 0.450 or 28.1 % Reduction of Area
M.T.S.
Y.P.
Cold Drawn in One Pass from 1/2" to 0.450 or 18.9 % Reduction of Area.
Thousands of Pounds per Square Inch
140
120
100
Curves of Cr-Va steel Drawn in One Pass then Reheated at Various Temperatures for 1/2 Hour and Quenched in Water
R A 19/32" to 0.450"
R A 17/32" to 0.450"
R A 1/2" to 0.450"
Per Cent
60
Elong. 19/32" to 0.450"
Elong. 17/32" to 0.450"
Elong. 1/2" to 0.450"
20
200
400
600
800
1000
1200
Degrees Fahr

Fig. 3—Curves of Chromium-Vanadium Steel Cold Drawn in One Pass, Reheated at Various Temperatures for 30 Minutes and then Quenched in Water. The Curves Labelled MTS, YP, RA and Elong. refer to Maximum Tensile Strength, Yield Point, Reduction of Area and Elongation, respectively.

in elongation and 4 per cent decrease in reduction of area. The manganese steel C gave 16,000 pounds per square inch or a 23 per cent increase in yield point, with 2 per cent increase in elongation and a 2 per cent decrease in reduction of area. The ten-

sile strength also increases slightly in each case; 4.2 per cent in the A steel, 8.7 per cent in the B steel, and 7 per cent in the C steel.

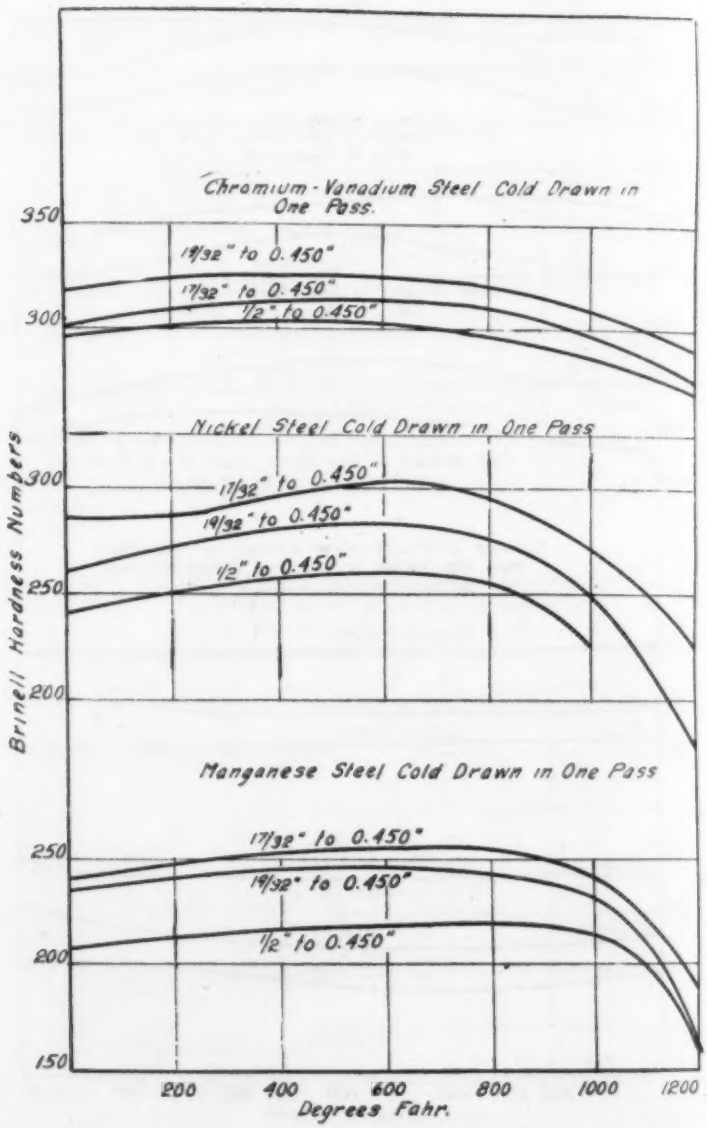


Fig. 4—Brinell Hardness Numbers of Bars Cold Drawn in One Pass, Reheated at Various Temperatures for 30 Minutes and Quenched in Water.

Nickel Steel

The yield point for the nickel steel A increases 17,000 pounds per square inch, or 16 per cent, with 3 per cent increase in elongation and no change in reduction of area. In the nickel

steel B, the yield point increases from 200 to 600 degrees Fahr., 20,000 pounds per square inch or 20 per cent, with 3 per cent increase in elongation and 4 per cent increase in reduction of

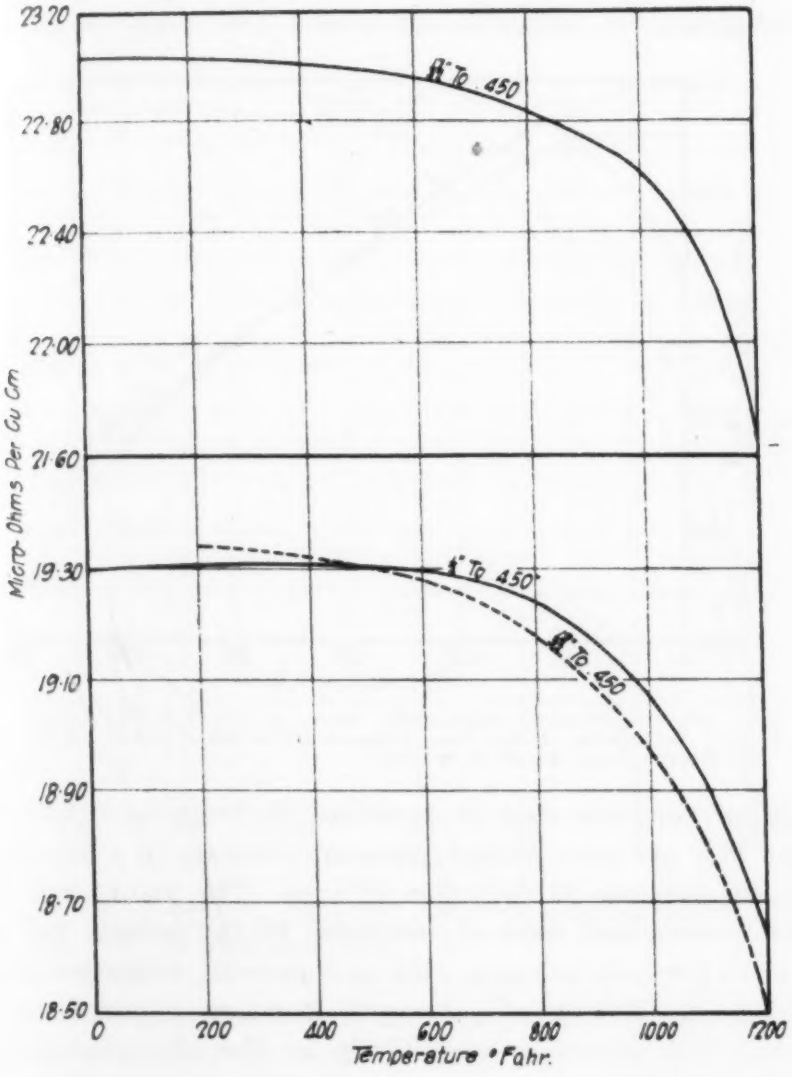


Fig. 5—Conductivity Curves of Manganese Steels, Cold Drawn in One Pass, Reheated at Various Temperatures and Quenched in Water. The Figures Shown Over Each Curve Indicate the Amount of Reduction the Bar Received in the Cold Drawing Operation.

area. In the case of the nickel steel C, the yield point increases 12,000 pounds per square inch, or 12 per cent, with 2 per cent increase in elongation, and no change in reduction of area. The tensile strength increases 6 per cent, 5½ per cent, and 7 per cent for the steels A, B, and C steels respectively.

Chromium-Vanadium Steel

The yield point for the chromium-vanadium steel A increases 22,000 pounds per square inch or 18.6 per cent, with no change in elongation or reduction of area. The yield point for the

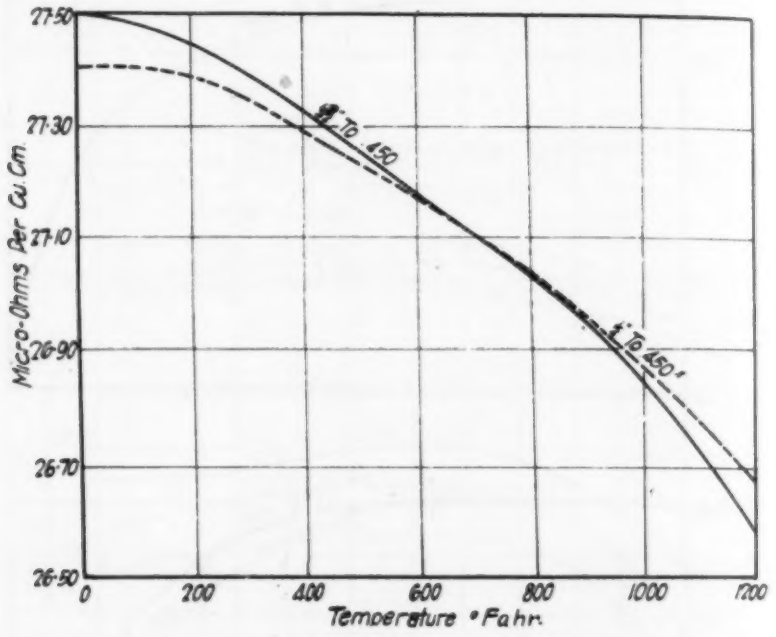


Fig. 6—Electrical Conductivity Curves of 3½ Per Cent Nickel Steel, Cold Drawn in One Pass, Reheated at Various Temperatures for 30 Minutes, then Quenched in Water.

chromium-vanadium steel B increases 21,000 pounds per square inch or 17.8 per cent, with 1 per cent decrease in elongation and 5 per cent decrease in reduction of area. The yield point for the chromium-vanadium steel C increases 16,000 pounds per square inch, or 14 per cent increase, with no change in elongation or reduction of area. The tensile strength increases 5 per cent, 4 per cent, and 5½ per cent respectively in the chromium-vanadium steels A, B and C.

The Brinell hardness figures similarly show the hardness to increase for reheating temperatures up to 600 degrees Fahr., then on further increase in re-heating temperatures to get progressively softer. The reheating temperature at which the Brinell hardness has fallen to the same figure as the stock as cold drawn varies from 800 to 1000 degrees Fahr.

Considering the tensile strength and yield point curves, we find we can reheat to temperatures from 900 to 1100 degrees

Fahr. and still have the same tensile strength and yield point, with no reheating, but at the same time get considerable increase in elongation and per cent reduction of area.

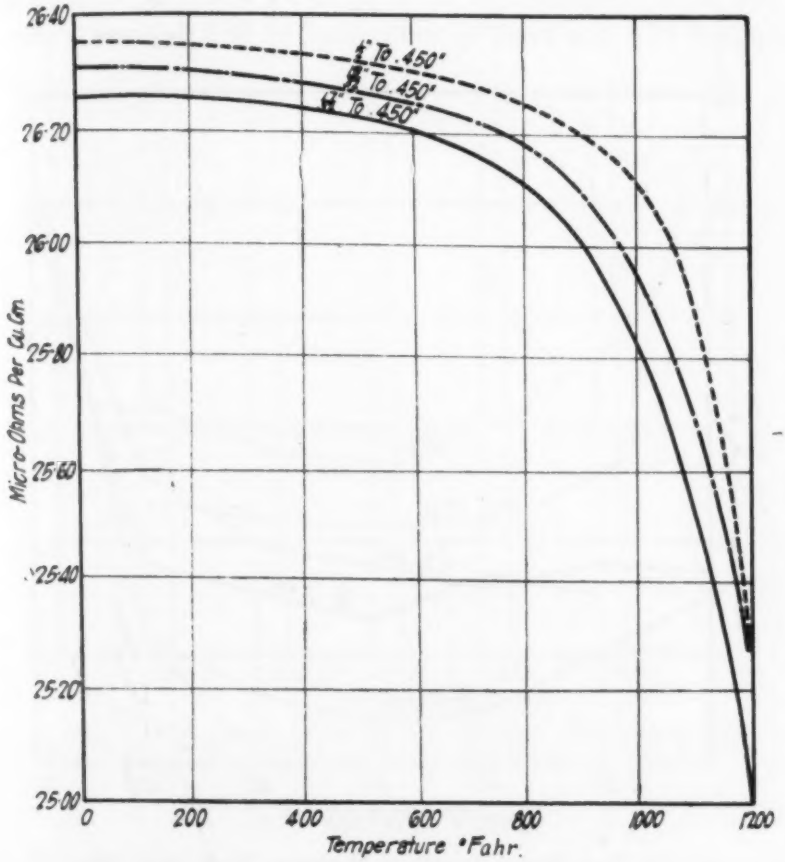


Fig. 7—Electrical Conductivity Curves of Chromium-Vanadium Steel, Cold Drawn in One Pass, Reheated at Various Temperatures for 30 Minutes, then Quenched in Water.

This does not seem to bear out the work of previous investigations, namely, that by short heating periods at 1100 degrees Fahr., practically complete restoration to the original softness occurs. The Brinell hardness of manganese steel A after 1100 degrees Fahr. anneal, is 215, while the hardness of the hot-rolled stock was 169.

With different amounts of cold work, it might be expected that as the amount of cold working is increased, the effect of reheating would be increased rapidly at first, then remaining about constant after a certain degree of cold working had been reached.

The results for the chromium-vanadium steels, in which the

chemical analysis is constant for all sizes, show that with 18.9 per cent reduction of area by cold working, the yield point is increased 14 per cent by reheating to 600 degrees Fahr. With 28.1 per cent reduction of area by cold working, the yield point is increased 17.8 per cent by reheating to 600 degrees Fahr. With

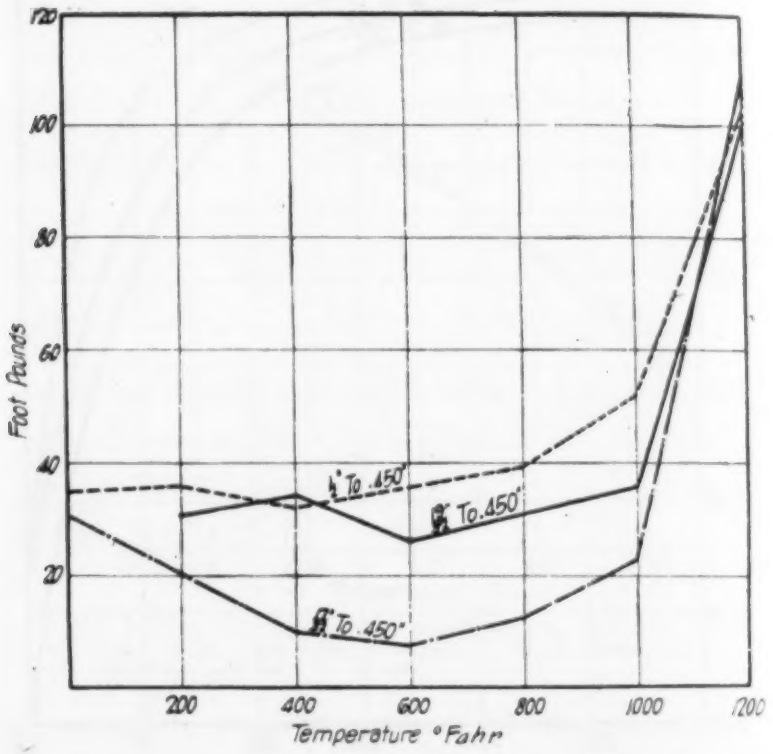


Fig. 8—Izod Impact Curves of Manganese Steel, Cold Drawn in One Pass, Reheated at Various Temperatures for 30 Minutes, then Quenched in Water.

42.5 per cent reduction of area by cold working the yield point is increased 18.6 per cent by reheating to 600 degrees Fahr.

The increase in yield point following reheating is slightly changed by increasing the amount of cold work from 28.1 to 42.5 per cent reduction of area. In both the nickel and the manganese B steels, the carbon and manganese contents are considerably higher than the A and C steels. Therefore, the results do not give a comparison of the effect of cold working on all sizes, but the results do show that higher carbon and manganese increase the effect of reheating by raising the yield point. For the other two, reductions by cold working, that is, 42.5 and 18.5 per cent, the manganese and nickel steels are similar to the chromium-

vanadium steel, or, in other words, if the amount of cold working is increased the reheating will have a greater effect in raising the yield point.

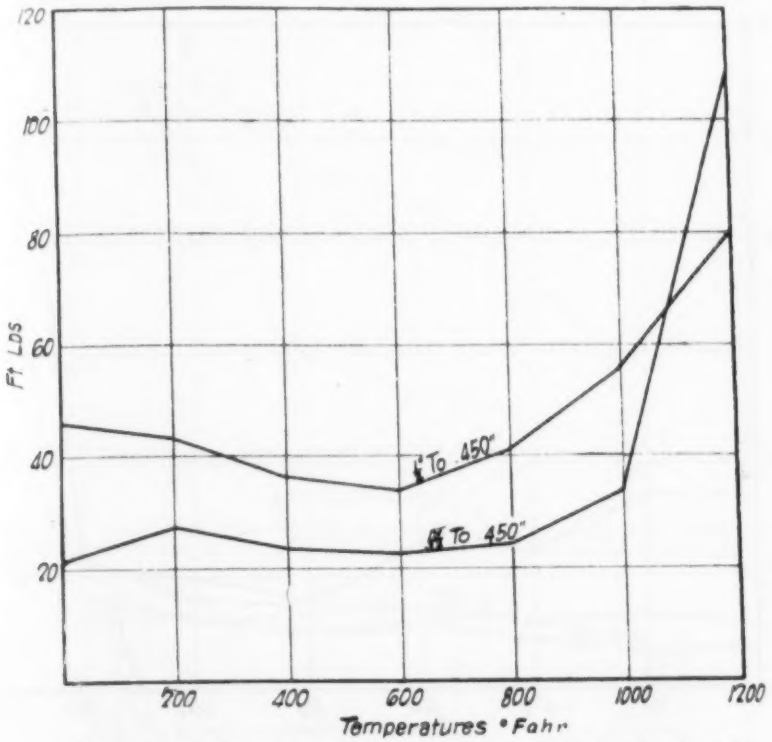


Fig. 9—Izod Impact Curves of 3½ Per Cent Nickel Steel, Cold Drawn in One Pass, Reheated at Various Temperatures for 30 Minutes and then Quenched in Water.

Izod Impact Tests

The Izod impact curves are the converse of the tensile and Brinell hardness curves (Fig. 11). Impact resistance decreases from no reheating to 600 degrees Fahr. (315 degrees Cent.) and then starts to rise slowly until at reheating above 1000 degrees Fahr. (540 degrees Cent.) it rises rapidly. At temperatures from 800 to 1000 degrees Fahr., the impact figure is approximately the same as with no reheating. The chromium-vanadium steel is an exception in that it does not begin to show increased impact values until a reheating temperature of 1200 degrees Fahr. (650 degrees Cent.) is passed. For a better comparison of the three kinds of steel, Izod values are plotted against yield point (Fig. 11). The manganese steel B is the poorest, the nickel steel considerably better, and the chromium-vanadium considerably the best of the three. For equal values of yield point, the chromium-

vanadium steel has the highest impact resistance, with the nickel steel next, and the manganese steel last. A decrease in the amount of cold work seems to increase the impact resistance.

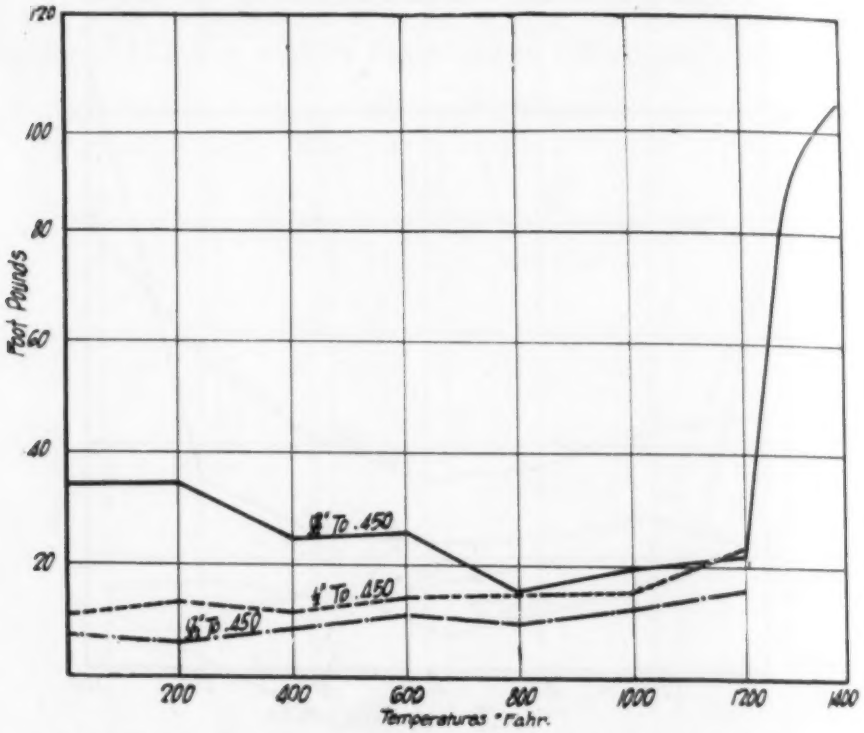


Fig. 10—Izod Impact Curves of Chromium-Vanadium Steel Cold Drawn in One Pass, Reheated at Various Temperatures for 30 Minutes and then Quenched in Water.

Electrical Conductivity Data

The resistance of a steel to electrical conductivity is the summation of the resistance of the solvent (ferrite) and the solutes (carbon, silicon, manganese, chromium, nickel, etc.), which are in solid solution in the ferrite.

Omitting the manganese steel B and the 3½ per cent nickel steels which are of considerably higher carbon content, it will be observed that all the other steels are of about the same composition in respect to carbon. As might be predicted from the chemical analysis, the 3½ per cent nickel steel with its high per cent of nickel in solid solution in the ferrite has the highest resistance. The chromium-vanadium steel comes next and the manganese steel last.

The electrical conductivity curves for the manganese and the chromium-vanadium steels are similar (Figs. 5 to 7). The re-

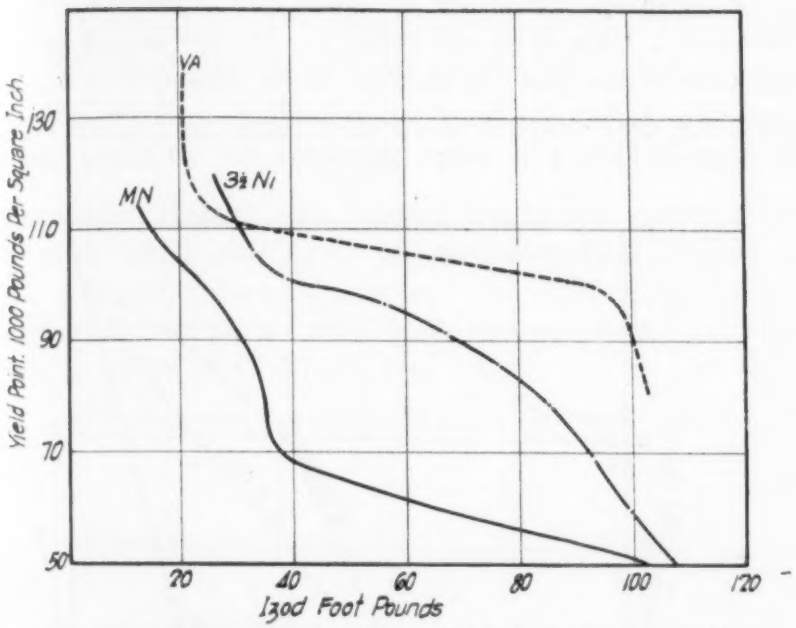


Fig. 11—Curves Showing the Relationship of Izod Impact to Yield Point on Cold Drawn Manganese, 3½ Nickel and Chromium-Vanadium Steels.

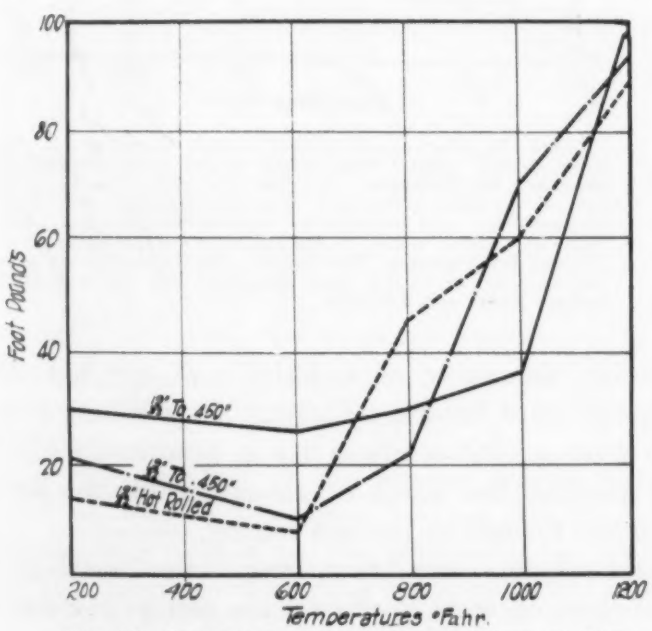


Fig. 12—Comparison of Izod Impact Values of Manganese Steel, Cold Drawn, and Then Reheated. All Bars Cold Drawn From 19/32 to 0.45 inches in One Pass. In the Solid Line Curve the Bar, After Cold Drawing, Has Been Reheated at Various Temperatures. In the Dot and Dash Line Curve, the Bar After Cold Drawing Has Been Quenched at 1625 Degrees Fahr. Into Oil and then Reheated at Various Temperatures. The Dotted Line Curve is that of the Hot-Rolled Bar Quenched at 1600 Degrees Fahr., and then Reheated at Various Temperatures.

sistance decreases slowly up to about 800 degrees Fahr. (425 degrees Cent.), then falls off rapidly. In the nickel steel the resistance decreases more uniformly at all temperatures. The total decrease in resistance from no reheating to 1200 degrees Fahr. (650 degrees Cent.) is about the same for all three steels.

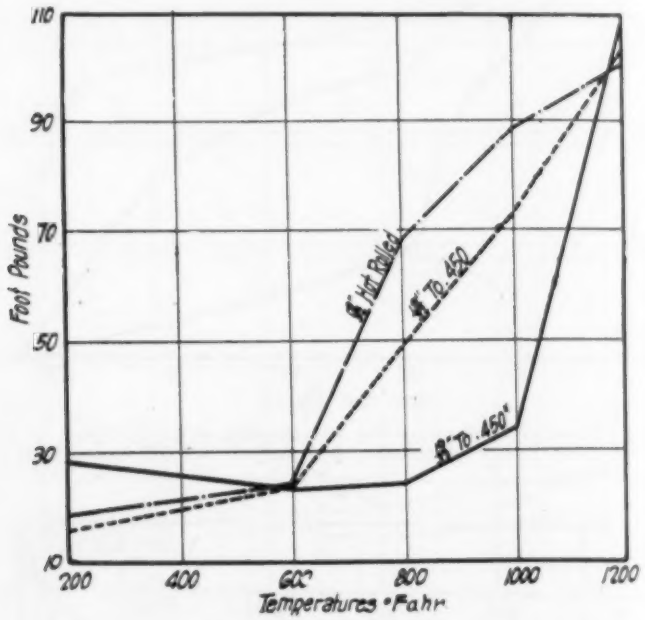


Fig. 13—Comparison of Izod Impact Values of 3½ Per Cent Nickel Steel, When Cold Drawn and Hot-Rolled, Quenched and Reheated. The Dot and Dash Line Curve is that of the Steel Hot-Rolled, Quenched Into Oil from 1525 Degrees Fahr. and Reheated at Various Temperatures. The Solid Line Curve is that of the Cold Drawn Bar Reheated at Various Temperatures. The Dotted Line Curve is that of a Bar Cold Drawn in One Pass, Quenched Into Oil from 1525 Degrees Fahr. and Reheated.

Comparing the value of resistivity of the hot-rolled rod to the cold drawn wire before reheating, it is found that the effect of the cold work on the conductivity is practically nil. The curves probably represent the effect of reheating on the sorbitic structure of the wire formed in the hot rolling.

For microscopic examination, longitudinal sections were taken from the unstrained ends of the tensile test pieces and are shown in the photomicrographs, Figs. 15 to 23.

The structures show clearly the effect of cold work in causing plastic deformation of the ferrite, the grains being elongated in the direction of drawing. Reheating at 600 degrees Fahr. (315 degrees Cent.) causes only a slight change in the structure

while after reheating to 1200 degrees Fahr. (650 degrees Cent.) there is considerable reversion to the normal structure.

Effects of Heat Treatments on Cold Drawn and Hot-Rolled Steel

To determine whether cold drawing would have any particular effect on stock which was to be subsequently heat treated, cold drawn and hot-rolled bars were taken from each of the A steels, from which standard three-notch Izod impact pieces were made. The results are plotted in Figs. 12 to 14.

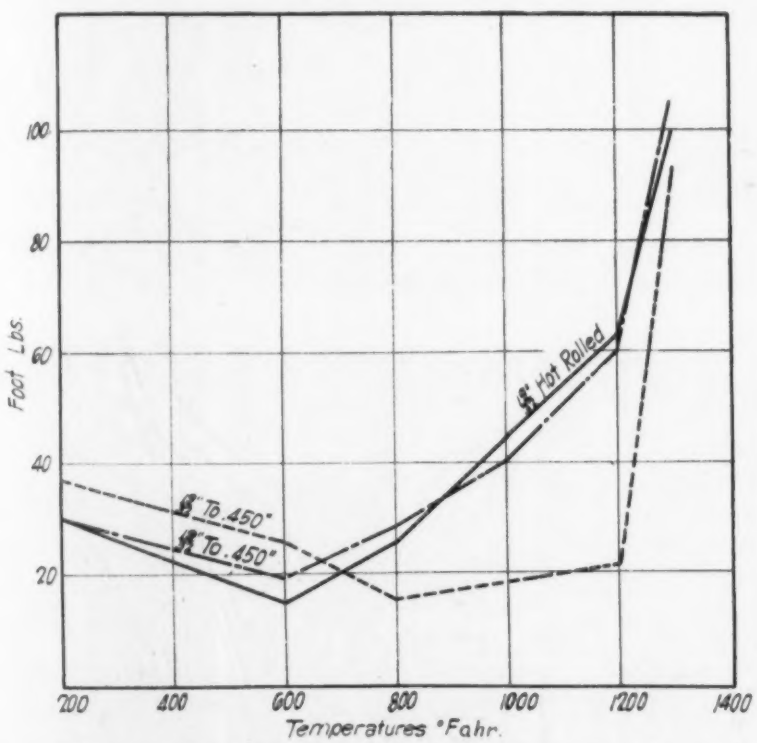
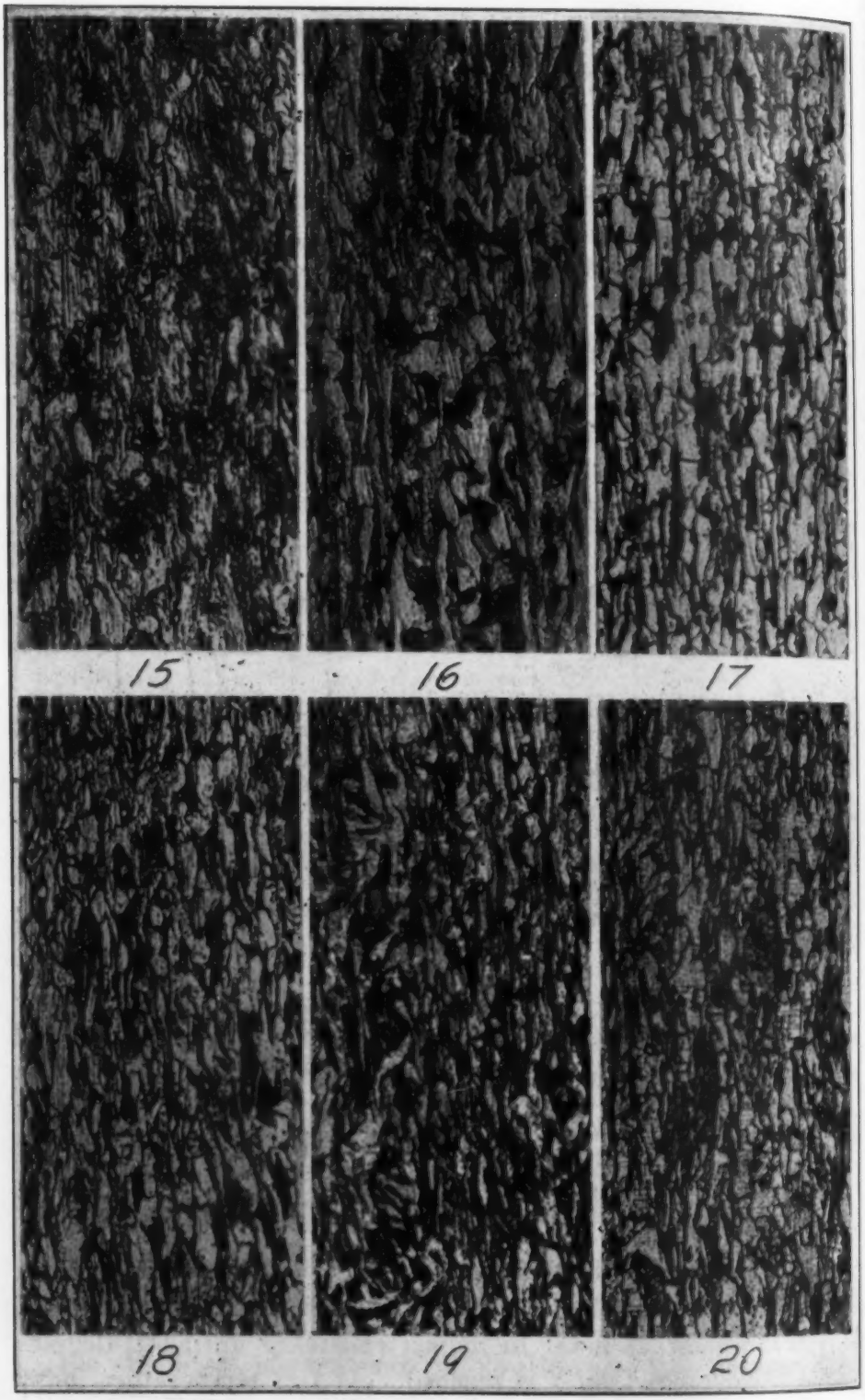


Fig. 14—Comparison of Izod Impact Values of Hot-Rolled and Cold Drawn Chromium-Vanadium Steel Bars that have been Quenched and Reheated. The Solid Line Curve is that of the Hot-Rolled Bar Quenched into Oil from 1625 Degrees Fahr., and then Reheated at Various Temperatures. The Dot and Dash Line Curve is that of the Cold Drawn Steel Drawn in One Pass and Quenched into Oil from 1625 Degrees Fahr., then Reheated at Various Temperatures. The Dotted Line Curve Represents the Cold Drawn Steel Which has been Cold Drawn in One Pass and then Reheated at Various Temperatures.

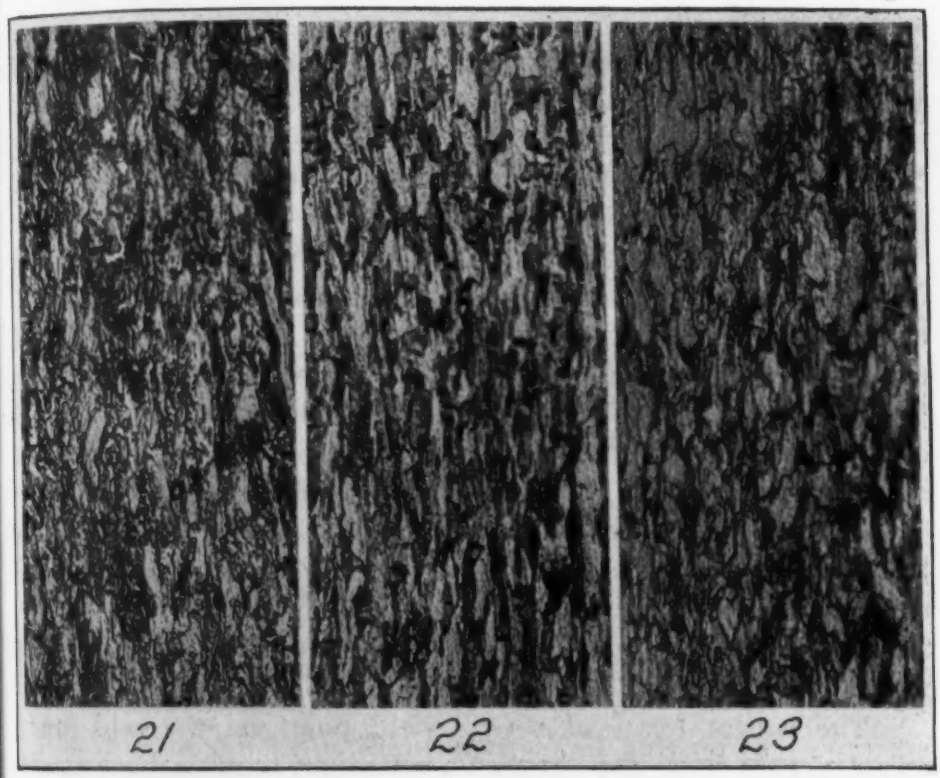
These curves indicate that the hot-rolled and cold drawn pieces behave identically toward heat treatment. The heat treated material is somewhat lower in impact resistance until 600 degrees Fahr. (315 degrees Cent.) is reached. At this temperature, however, the impact values for the manganese and nickel steels rise



Figs. 15, 16 and 17—Photomicrographs of Manganese Steel Cold Drawn in One Pass from 19/32 to 0.45 inches. Fig. 15—As Drawn. Fig. 16—Tempered at 600 Degrees Fahr. Fig. 17—Tempered at 1200 Degrees Fahr. Figs. 18, 19 and 20—Photomicrographs of 3½ Per Cent Nickel Steel Cold Drawn in One Pass from 19/32 to 0.45 inches. Fig. 18—As Drawn. Fig. 19—Tempered at 600 Degrees Fahr. Fig. 20—Tempered at 1200 Degrees Fahr. All Magnifications 250x.

rapidly, while the cold drawn stocks remain comparatively low. When 1000 degrees Fahr. (540 degrees Cent.) is reached for the cold drawn manganese and nickel steels, the impact values are rapidly increased. This temperature for the cold drawn chromium-vanadium steels is 1200 degrees Fahr. (650 degrees Cent.).

It is interesting to note that the impact resistance for the chromium-vanadium steel starts to increase when tempered at 600



Figs. 21, 22 and 23—Photomicrographs of Chromium-Vanadium Steel Cold Drawn in One Pass from 19/32 to 0.45 inches. Fig. 21—As Drawn. Fig. 22—Tempered at 600 Degrees Fahr. Fig. 23—Tempered at 1200 Degrees Fahr. All Magnifications 250x.

degrees Fahr., which is also true of the manganese and nickel steels. These steels in the cold drawn condition lag 200 degrees Fahr. behind the other steels, until 1000 degrees Fahr. is reached, except for the chromium-vanadium steels, which requires a temperature of 1200 degrees Fahr.

The results of this work indicate that cold drawn material will behave in the same manner in heat treating as hot-rolled bars. Therefore, it would seem that cold drawing, even in heavy drafts, is in no way injurious to a material which is to be heat treated.

Summary

The manganese, 3½ per cent nickel, and the chromium-vanadium steels, cold drawn and reheated to 600 degrees Fahr., gain considerably in yield point with only slight increase in tensile strength and a slight loss in ductility and notched-bar toughness. At 1000 and 1100 degrees Fahr. (540-595 degrees Cent.) the yield point and tensile strength have been reduced to their initial figures, while the ductility and notched-bar figures have been greatly increased. Reheating over 1100 degrees Fahr. (595 degrees Cent.) causes the yield point and tensile strength to fall rapidly and the ductility and notched-bar figures to increase. The chromium-vanadium steel is an exception, requiring a temperature of 1200 degrees Fahr.

The curves for the hot-rolled and cold drawn stock show that they both respond to heat treatment, practically identically. This would indicate that the effects from cold working are entirely removed by heat treatment. Comparing the heat treated bars with those simply reheated after cold drawing, it will be observed that at low reheating temperatures the Izod values are higher for the reheated bar, but beyond a reheating temperature of 600 degrees Fahr., the heat treated bar rises rapidly, while the Izod resistance for the cold drawn, reheated manganese and nickel steels bars do not increase rapidly until a temperature of 1000 degrees Fahr. is reached. This temperature for the chromium-vanadium steel being 1200 degrees Fahr.

The curves for Izod versus yield point on the cold drawn reheated bars show the chromium-vanadium steel to have considerably the highest impact resistance for a yield point under 110,000 pounds per square inch. For values over 110,000 pounds per square inch the nickel and chromium-vanadium steels are about the same. The manganese steel is considerably lower in impact resistance at all yield points.

Grossmann[6] shows by impact tests that brittleness is increased by reheating hardened alloy steels in the neighborhood of 600 degrees Fahr. He ascribes this phenomenon to the change of austenite, which has been retained, to martensite. By a series of length measurements on hardened and tempered test pieces, he found a volume increase occurring at this temperature, which

[6]M. A. Grossmann, "Brittle Range in Low Alloy Steels," *Iron Age*, July 17, 1924.

he interprets as the formation of martensite from austenite. As this change is found at the same temperature at which minimum shock resistance occurs, he connects the two phenomena as cause and effect. While it is possible that austenite is formed on the quench and that it may show up by a volume increase at low tempering temperatures, it does not seem necessarily true that this change which is occurring at the same time as the transformation of original martensite would necessarily result in brittleness. Looking over the Izod results in this paper it is noted that a minimum Izod value was found on cold drawn material which had not been quenched. This minimum generally occurs at 600 degrees Fahr., which is the same point at which minimum Izod is found on quenched and drawn samples. If this phenomenon were found on bars which had never been quenched and, hence, could not contain austenite, it would seem as though the minimum Izod which Grossmann has ascribed to austenite changing to martensite might be due to some other cause. What this cause is, the author has not been able to definitely establish, but simply wishes to point out that it may occur where presumably no austenite or martensite is present.

Conclusions

1. The yield points for the manganese, 3½ per cent nickel, and the chromium-vanadium steels are considerably increased after cold drawing and reheating to 600 degrees Fahr. (315 degrees Cent.). The tensile strength is only slightly increased. There is a slight loss in the ductility and notched-bar toughness.

2. At 1000 and 1200 degrees Fahr. (540 and 595 degrees Cent.) the yield point and tensile strength are reduced to their initial figure, while the ductility and notched-bar figures have made considerable gain over their initial values.

3. Reheating over 1200 degrees Fahr. (595 degrees Cent.) causes the yield point and tensile strength to fall rapidly and the ductility and notched-bar figures to increase.

4. The chromium-vanadium steels require a higher reheating temperature to restore their normal physical condition (a proper balance between the tensile strength and ductility).

Written Discussion:—By R. S. Archer, Aluminum Company of America, Cleveland.

Mr. Spalding has presented a paper of considerable practical and

theoretical interest. There are a number of points on which the writer would like to make brief comments.

On heating cold-worked iron or steel two distinct effects are known to take place. There is first a general increase in hardness and loss in plasticity in the blue heat range which is then followed on heating at higher temperatures by a decrease in hardness and increase in plasticity ending in substantially complete softening at the temperature of full recrystallization. Similar effects take place in other cold-worked metals, notably in brass, although the hardening effect of reheating at low temperatures is not nearly so great in the case of the other metals as in the case of iron and steel.

In the present paper the increase in hardness and related properties such as yield point and the decrease in ductility and impact values in the blue heat range do not seem to have been identified with results previously described on the heating of overstrained or cold-worked iron and steel. In considering the effects of heating after cold working it should be kept in mind that cold-worked iron and steel undergo an increase in hardness and decrease in plasticity spontaneously on standing at ordinary temperatures. This spontaneous change is quite slow, and it is therefore a matter of some importance to know how much time has elapsed between the cold drawing and the testing of the material in the "as drawn" condition. It is possible that if sufficient time elapsed before testing, the increase in hardness, which reached a maximum after heating at 600 degrees Fahr. in Mr. Spalding's work, would not take place at all, or at least would be less marked.

The author has called attention to the fact that his cold drawn materials did not recover their original softness at as low a temperature as did the cold drawn wires described by Goerens. This can perhaps be explained by the facts that Mr. Spalding was dealing with alloy steels, whereas Goerens was dealing with substantially pure iron-carbon alloys, and that Mr. Spalding's samples did not receive reduction by cold drawing greater than 48 per cent, whereas the wires tested by Goerens received much greater reductions. It is well known that the temperature of recrystallization of a cold-worked metal or alloy is lower the greater the amount of cold working, other things being equal.

The writer considers that Mr. Spalding's conclusions to the effect that the cold drawn rods responded to heat treatment in the same manner as the hot-rolled bars are open to question. The results actually given show that in the case of the manganese steel and the nickel steel, the results obtained after heat treatment are not by any means identical for the two kinds of material. After hardening and drawing at 800 degrees Fahr., for example, the manganese steel heat treated after hot rolling shows an impact value more than twice as great as the same steel heat treated after cold drawing. A similar discrepancy is shown by the nickel steel, although not so great in magnitude. The results on the two kinds of material are substantially the same in the case of the chromium-vanadium steel.

The changes in electrical resistivity on heating after cold drawing are of considerable theoretical interest. It will be noted that in all cases the author has found a lower resistivity after heating the cold drawn rod to 600 degrees

Fahr. than be found on the rod as drawn, while at the same time the hardness is greater. Similar results have been obtained on Armco iron wire in some student research work under the direction of Professor Boylston of Case School of Applied Science. This is consistent with the suggestion advanced by Dr. Jeffries and the present writer, that the hardening or elastic recovery after overstrain is due to a "healing" process on the slip planes.

Mr. Spalding has called attention to the fact that he found minimum impact values after heating at 600 degrees Fahr. on cold drawn steels which could not have contained austenite, and from that fact questions Grossmann's conclusion that the embrittlement of certain alloy steels on tempering at 600 degrees Fahr. is due to the conversion of austenite to martensite. It seems to the writer that these are two entirely distinct phenomena. Grossmann was dealing with hardened steel which almost certainly contained some austenite. It is quite to be expected that this austenite would decompose to form martensite or troostite on reheating. The increases in length observed by Grossmann were probably due to such conversion. It is also to be expected that such conversion would cause brittleness. On the other hand, the embrittlement of cold-worked iron or steel by heating in the blue heat range is well known. This effect is definitely associated with cold working, and takes place in pure iron as well as in steel. Grossmann's samples were not cold-worked. It does not even seem permissible to consider any internal cold working due to the hardening. If such cold working could cause brittleness on reheating, then this brittleness should be observed in a water quenched carbon steel, for example, where the quenching is more drastic and the internal cold working, if any, should be more severe.

Oral Discussion

W. J. MERTEN: It seems unfortunate that the author did not employ an autographic instrument for plotting the tensile test curves. If he had, he would probably have found some evidence which would have a bearing upon the results he obtained. I am also surprised to hear the author remark that he has not found any evidence in the literature bearing on this subject, because there are a number of papers dealing with the subject of relieving of strains in cold-worked metals all of which deal with the phenomena, which he claims to have discovered. It will be found on an autographic curve (illustrating) that cold-worked steel has a low proportional limit and a large radius of curvature, and on heating this material, even to temperatures around 200 degrees Centigrade or even lower, it will relieve the internal strain and raise the proportional limit so that it practically coincides with the yield point. Strain relieving of cold-worked steel and the accompanying changes in physical values are apparently the phenomena that has been encountered and published information of results of similar kind is available. Alloy steels as well as ordinary carbon steels respond to very low temperature treatment for the relieving of strain and may even result in structural disturbances.

DR. V. N. KRIVOBOK. Last year I became much interested in the study of cold drawn steels from the point of view of thermal analysis of such steels. It seems to me that if I describe as briefly as possible the way it has been

done and the results obtained, the additional information may be of interest in connection with the valuable paper we have just heard.

Although the results obtained in the laboratories of the Bureau of Metallurgical Research have no direct bearing upon the paper of Mr. Spalding, yet they give very interesting evidence of a theoretical nature in support of his work.

Several iron alloys were selected for the investigation to be presently described. Most of the work was done on Armco iron and steels with 0.20 and 0.50 per cent carbon. Some of these steels were in the "cast" condition, some as "hot-rolled". The steels were cold-worked so that the original sample was reduced about 50 per cent in cross section. This gives an idea of the total work imparted to the sample. Then a sample for the determination of critical points was turned from the cold-worked material. Immediately after that the sample was put in an ordinary critical point apparatus, which was adjusted to fairly high sensitivity and the critical points of the samples of steel were determined. In this way a very interesting phenomenon was recorded.

In the steels (and also in the Armco Iron), which were cold-worked as described, a pronounced thermal disturbance usually occurring just below Ac_1 was found, but opposite in sign. That is, on heating a sample of steel, absorption of heat takes place at the Ac_1 point, while in the cold-worked samples there was a decided evolution of heat just before the Ac_1 point was reached. If, however, cold-worked material of, let us say 0.30 per cent carbon were allowed to lay around for several days and then subjected to thermal analysis, no abnormal critical point was observed, and the cold working did not seem to have any effect whatsoever. The numerous photomicrographs taken from the samples at the different stages of the investigation show that the phenomenon just described was accompanied by a decided change in the structure of the samples. I believe that I can observe somewhat similar changes in the photographs shown by Mr. Spalding, but he does not make the specific mention of the fact.

If we take the cold-worked steel and heat it just below this abnormal critical point, we will find no change whatsoever in the appearance of the structure of the sample. It has the regular structure of cold-worked steels. But, if we heat it just above the new critical point which I described, the breaking up of large and elongated grains of ferrite will take place immediately to such an extent, in fact, that the cold-worked structure is entirely obliterated. A big grain of ferrite will be subdivided; that is, recrystallized into smaller ferritic grains. In view of the facts just related it is natural that we should find some change in the mechanical properties of steels as described by Mr. Spalding.

Of course, I did not work with the same steels as Mr. Spalding. My investigation was limited to plain carbon steels. However, the steels which are described by Mr. Spalding contain some free ferrite. In photomicrograph 17 which represents a manganese steel we find that the ferrite has recrystallized. The same recrystallization does not seem to have taken place in the sample shown in photomicrograph 16. The sample was heated just below this newly observed critical point.

I have, I am sorry to say, no theory to offer for the appearance of the new critical point, except that the recrystallization of the ferrite which takes place in the solid state has undoubtedly some bearing upon the phenomenon observed. I am inclined to think, however, that in every cold-worked steel a change takes place, upon annealing, in the amount and distribution of the internal energy.

At present I am trying various methods in an attempt to throw some light on the distribution and the amount of free energy in the samples of steels as "cold-worked" and as "annealed". Should these researches be successful we may have some additional knowledge on the ever-interesting question of cold working of steel.

Because this question is all-important, I would like to voice my appreciation of the valuable paper delivered by Mr. Spalding.

J. A. REINHARDT: Mr. Spalding's paper is particularly interesting to me, as was the discussion by Mr. Archer, because I have encountered the problem under consideration from an entirely different angle, i. e.; the effect of cold working with subsequent heatings on the sounding qualities of gong steel after fabrication. I happen to be with the Western Clock Co. and we found after the war that the average cold rolled strip steel resulted in very poor sounding gongs.

A thorough investigation developed the following cures for dead sounding gongs:

1. Heating to temperatures between 900 and 1000 degrees Fahr. for 10 minutes and then quenching. (Molten sodium nitrate was used as the heating medium.)

2. Additions of phosphorus from 0.05 to 0.09 per cent to ordinary strip steel analysis.

3. Allowing the gongs to age for six months after fabrication. (This treatment is not a sure one as the poor sounding gongs laid away did not give 100 per cent good sounding gongs).

It is the investigation of the first cure that we are interested in here, as it has direct bearing on the paper being discussed. In order to have something definite to offer, supplementary to the extemporaneous discussion based on earlier superficial tests, Rockwell hardness tests have since been made upon two different types of low carbon steel after various heat treatments, and are introduced here. It was found necessary to take Rockwell readings rather than yield points, but it is felt that the properties revealed thereby are sufficiently comparable, for this discussion, to those revealed by the yield point data.

The steels used were: (A) (0.022 inch thick) of the ordinary cold-rolled strip steel analysis which gives uniformly bad sounding gongs and (B) (0.045 inch thick) the newly developed steel which gives uniformly good sounding gongs. Their compositions:

	(A)	(B)
Carbon	0.08 Per Cent	0.08 Per Cent
Manganese	0.33	0.44
Phosphorus	0.020	0.068
Sulphur	0.018	0.043

The tables which follow show the result of cold work and reheating. The cold working is, of course, not as thorough as Mr. Spalding's, consisting merely of a folding and deforming of the flat piece of steel into the cup like side of the gong. Due to such non uniformity of working the variation in Rockwell readings are natural. The averages can be taken, however, as true indications of the condition.

The normalizing of the samples was accomplished in a sealed pot at 1650 degrees Fahr. for 5 hours followed by slow cooling in a reducing atmosphere. The subsequent heatings were accomplished in molten sodium nitrate. This latter heating forms a very light blue scale on the steel which is not of appreciable thickness. The readings on each sample represent from 5 to 7 tests.

Table I

Sample Number	Description of Initial Condition	C 100 1/16" ROCKWELL VALUES			
		Initial Condition	First heat, 10 min. at 965° Fahr., quenched in water	Second heat, 10 min. at 965° Fahr., quenched in water	Third heat, 2 hrs. at 925° Fahr., cooled in air
1	Low Phos. Steel	40½–42½	58 –61	61 –63	60 –62
2	(A) Normalized	47 –48	62½–66	65 –67	64½–67
3		47 –51	64½–65½	65 –66½	62 –64
4		44 –46	61½–63½	64½–66	60 –62
5		41 –47	60½–63	59 –64	60 –63
6	Low Phos. Steel	64 –74	74½–79	75 –77	73 –75
7	(A) Normalized	68 –80	77 –85	76 –85	73 –77
8	and then cold	65 –74	76 –82	71 –80	70 –76
9	worked	66½–72	74½–78	77 –79	72 –74½
10		69 –73	75½–78	77 –80½	75 –77
11	High Phos. Steel	54½–57½	60 –61½	59 –62½	58 –64
12	(B) Normalized	56 –58	61½–65	60 –64	64 –71
13		56 –60	60 –66	62 –64	60 –68
14		54 –58	57 –66	61 –66	60 –66
15		53 –58	56 –62	57 –62½	58 –61
16	High Phos. Steel	76 –86	78 –82½	78 –85	82 –86
17	(B) Normalized	76 –83	78½–82	77 –81½	76 –84
18	and then cold	82 –85	82½–85½	82½–86	81 –83½
19	worked	79 –85	80 –85	79 –85	79 –82
20		82 –87	83½–86½	.....	79 –82

The results given in Table I. are rather startling. Instead of showing the increase in hardness after heating to be entirely due to cold working as found by Mr. Spalding, the increase in hardness here is seen to be greater in the normalized, non-worked steel. In the case of the high phosphorus cold-worked steel (samples 16 to 20) absolutely no hardening effect due to heating is discernible, while in the same steel the normalized samples (11 to 15) show an appreciable hardening effect.

This would indicate that we have to do rather with some of the minor

critical ranges in the steel than with any effect of cold working. Dr. Sauveur cites a number of these minor critical ranges which have been discovered but dismisses them with the statement that "their existence is not fully estab-

Table II

Sample Number	Description of Initial Condition	C 100 1/16" ROCKWELL READINGS	
		Initial Condition	10 minute heat at 975° F. and cooled in air
21	Low Phosphorus Steel (A) Normalized	37–44	58–62
22		37–40	56–58
23		38–42	53–57
24		39–42	56–58
25	Low Phosphorus Steel (A) Normalized and Cold Worked	73–79	75–78
26		73–77	70–78
27		71–79	74–79
28		72–78	70–79
29	High Phosphorus Steel (B) Normalized	64–66	67–72
30		64–67	68–73
31		63–66	68–70
32		63–67	68–72
33	High Phosphorus Steel (B) Normalized and Cold Worked	82–86	.....
34		84–87	81–85
35		80–83	80–82
36		79–87	75–88

lished."* Granting for a moment that their existence is established, it is quite conceivable that the phosphorus content affects these critical ranges (it is certainly suggested by the results presented here) and that in the alloy steels the character and position of the ranges may be completely changed.

The tests shown in Table II. were made to determine the effect of quenching on the hardening. It is quite clearly shown that quenching has no effect on the phenomenon, and the investigation is thereby further complicated.

Mr. Archer suggests that the hardening effect may be due to the healing of the slip bands in the cold-worked metal. It is possible that this effect may take place in the instance where good sound is restored by aging, but this is also open to serious question due to the influence of phosphorus which is noted.

It is hoped that these remarks may stimulate further investigation of the subject, and it will be my endeavor to present the subject more fully at some future time.

A. L. DAVIS: This paper has been a very interesting one to me, and is one of general interest. I think we will have to agree that there has been a little something in literature that one could have drawn upon. Howe states that cold-rolled steels, cold deformed steels, slowly increase in strength on aging, (as has been pointed out by Mr. Archer), and also more rapidly on heating, which makes the aging effect take place more rapidly.

*"The Metallography and Heat Treatment of Iron and Steel," 1918 edition, page 167.

This effect has been found by many individual investigators, in ferrous metals, also slightly in nickel, and more or less in brass.

One thing that strikes me is that it is very valuable to have the facts presented, even if we cannot set forth a theory. If we only collect the facts and get them down, somebody will be able to look them all over and build a theory after enough are collected; so I do not think the author of the paper or anybody else need be apologetic for not being able to present a full-blown theory.

One point in Mr. Archer's discussion appealed to me. He spoke of the explanation as suggested by himself and Dr. Jeffries of the increase in strength upon aging and more rapidly upon mild heating of cold-formed steels and some other metals, as a "healing" effect, which sounds plausible—I see no other explanation. But Mr. Archer also mentioned that, simultaneously with this increase in strength we find, as the author of the paper notes, also a slight increase in brittleness; not a hot brittleness, but in the cold. Now, I will admit that I am not able to grasp the reason for this. I could see why "healing" would make metal stronger, but not why "healing" should make it more brittle. I am wondering whether Mr. Archer or somebody can throw some light on that point.

J. D. ARMOUR: I notice that several men have reported results they have obtained on cold-worked material which show an increase in yield point and tensile strength after heating at low temperatures, and I would like to ask if they have considered the effects of acid brittleness. If the cold work was preceded by a pickling operation to remove scale the effects of acid brittlness may show up in the cold-worked tests which had not been heated, while the acid brittleness would be removed from the heated pieces and they would therefore show a change in physical properties.

CHAIRMAN JEFFRIES: This discussion has brought forth a number of points, and before asking Mr. Spalding to close, I would like to offer a few remarks on this general subject.

In the first place the question of the removal of strain is something which has been very much over-worked. It was the expression that was used for years when we knew of nothing better to use, and it is still used to a large extent to explain in words, so as to satisfy one's own conscience, perhaps, something which he cannot explain any other way. Now, we do not want to evaluate the matter of strain in any but the correct way. That is, we realize that there are such things as internal strains in metals, but we also would like to know just how much weight to attach to internal strains and not try to attribute to internal strains things and effects which they are not responsible for.

One of the great difficulties in associating general internal strain with these changes which Mr. Spalding has described is the variable effect in different materials. The cold working of iron and steel should not induce any more internal strain than the cold working of certain other nonferrous metals, nickel, monel metal, etc. A comparison between such metals and iron gives us a method for more or less evaluating the strain portion of this complex, so that the results obtained with iron and steel, being absolutely unique among

all of the metals, make us resort to some other explanation in order to account for these relatively tremendous changes in percentage, which obtain in iron and steel.

There is one point in connection with Mr. Spalding's results on which I am not thoroughly clear, and for the benefit of the whole meeting as well as myself, I will ask Mr. Spalding to answer for us a question, so that we can all be enlightened. What were the treatments to which the samples of steel were subjected prior to the treatments which you refer to as increasing the hardness?

S. C. SPALDING: Some of the steel was cold-worked and some was quenched from above the critical temperature.

W. J. MERTEN: In regard to the difficulties of relieving internal strain present in large masses in the hot-worked condition, may I say that normalizing followed by reheating and furnace cooling will not relieve these strains in very large steel bodies. I have in mind a problem involving the relieving of strains in very large forgings of approximately 52 inches in diameter and about 150,000 pounds in weight, which forging after a triple heat treatment, including first normalizing, then reheating to above 1500 degrees Fahr. and furnace cooling and again reheating it to approximately 1250 degrees Fahr. and furnace cooling, still left an internal or residual stress of approximately 10,000 pounds per square inch in the external or peripheral section of this forging. It certainly illustrates how difficult it is to actually obtain complete relief of internal straining in any metal whether worked hot or cold. Subjecting the metal to a heating operation for a prolonged period of time will certainly effect a change both in tensile values in the elastic range as well as in the range of plastic flow under externally applied loads.

T. H. NELSON: The nail has been hit on the head by Mr. Merten, and I find myself in disagreement both with the chairman and Mr. Spalding on some of these points. The relief of tension is a very important factor, and, unfortunately, no metallurgical knowledge has enabled us to find a better term for it. I think we must agree that different conditions of tension or strain or density are obtained in materials of different analyses, and that these ferrous materials of different density and of different chemical analysis, having taken unto themselves a definite state of tension typical of that analysis, are equally different in the release of it at various temperatures. I have studied this subject and have quite recently done a lot of experimental work on steels of the higher chromium ranges, and I find exactly the same type of material. In some cases we get brittleness and in some cases toughness. I feel that the whole thing is entirely tied into the chemical analysis, just as one specimen will elongate more per foot than another, so do they take different tensions and so do they require different temperatures for the release of that tension.

CHAIRMAN JEFFRIES: Now, to get back to our point of common thought as to what was done, what Mr. Spalding made his tests on with somewhat similar results were cold-worked steel and previously quenched steel. Is that correct?

S. C. SPALDING: Yes.

CHAIRMAN JEFFRIES: And he finds similar, as he says, changes taking

place in the reheating of the two types of material.

Now, the additional thought which I wish to have before the members before Mr. Spalding closes is this, that these changes produced by cold work alone have been pretty well studied and they have been studied on fairly pure iron, in which there is not a great deal of opportunity for changes of constituents. The other possibility which readily comes to mind in connection with the interpretation of these results is that of solution and precipitation of some of the alloying elements present in the steel. The field of solubility of these various constituent elements in alpha iron, within the temperature ranges at which alpha iron is stable, is almost unexplored. We do not know accurately, for example, what the solubility of carbon is in alpha iron with variation in temperature from 700 degrees Cent. down to room temperature. We do not know the solubility of phosphorus within that range. We know the solubility of certain other constituents to be considerable, but the solubility variation of certain of these elements with change in temperature is a field which needs considerable attention at the present time.

For example, suppose we would consider that on cooling the steel, the cooling rate had been too rapid to allow for complete precipitation of some of the alloying elements which were in solution in the alpha iron at a temperature, say, of 700 degrees Cent. Now, on reheating and holding at a certain lower temperature for a time, some of that material might precipitate out in the form of small particles and cause increase in hardness, strength and yield point.

I just wanted to put that idea before the members before Mr. Spalding closed. I do not wish to appear in the position of answering the discussion for Mr. Spalding. I merely wish to point out in connection with this internal strain proposition that the effect is there in all metals which have been subjected to various processes, and no one denies the existence of it, but that the results on physical properties are so tremendously greater in the case of iron and steel than they are in other materials with analogous properties, such as elastic limit, that we feel that we can give that matter of internal strain somewhat of an evaluation at this time which would put the evaluation at something very much under that which would be necessary to account for the changes in properties observed on ferrous products.

Mr. Spalding, I think we are ready for your closure.

S. C. SPALDING: I have nothing very much to say in conclusion. As far as Mr. Archer's suggestion is concerned that possibly time and aging might have brought the steel to a stable condition so that the reheating temperature would not have affected it, I would say that these tests were made several months after the material had been cold drawn. It is possible that if the time had been long enough, this effect might have occurred, but apparently several months' time is not sufficient to have much aging effect.

As far as the effect of pickling is concerned, I do not think that enters in this case, for in some of our experiments we have taken annealed carbon steel drill rod, material which is a straight carbon tool steel that has had perhaps three to four annealings and only been pickled back before the first

(Continued on Page 780)

INFLUENCE OF HEAT TREATMENT AND CARBON CONTENT ON THE STRUCTURE OF PURE IRON-CARBON ALLOYS

By W. L. Fink and E. D. Campbell

Abstract

X-ray patterns were obtained from a series of pure iron-carbon alloys varying only in carbon content. Photomicrographic records were made of the identical surface used for X-ray work.

The changes in the alpha iron lattice, the presence of gamma iron lines, the changes in the gamma iron lattice, and the presence of carbide lines were all observed. Moreover, a body-centered, tetragonal structure, not previously observed, was found in high carbon, water-quenched steels. The observed facts were correlated with the carbon content and heat treatment.

Historical Review

THE idea that crystals are built up by an orderly arrangement of minute particles was first proposed by Robert Hooke[1] (1) in 1665, and the possible arrangements for alum were shown. In 1801, Hauy (2) expressed the same idea, and developed the theory more in detail than Hooke had done. He named the particles from which the crystals are built: "Molécules Intégrant," and the elementary particles which combine to form these "Molécules Intégrant" he called "Molécules Eléméntaires."

During the interval from 1801 until the advent of X-ray methods in 1912, the idea became firmly established and a theory completely worked out by Frankenheim (3), Bravais (4), Sohncke (5), Schoonflies (6), Fedorov (7), Barlow and Pope (8), and others, concerning the possible space lattices and point systems, according to which these minute particles could be arranged. It was shown that there were fourteen possible space lattices, and 230 point groups. There was, however, no way of determining the number of molecules in one structural unit, nor the absolute spacings.

[1]The figures appearing in parentheses refer to the corresponding number in the bibliography appended to this paper.

A paper presented before the Winter Sectional Meeting of the Society, January 21 and 22, 1926, at Buffalo, N. Y. The work presented in this paper was done by W. L. Fink under the supervision of the late Professor E. D. Campbell, and submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in the University of Michigan.

These determinations waited for the development of X-ray methods which were introduced by the well-known experiment of Friederick, Knipping and Laue (9, 10) in 1912. In the years immediately following, W. H. Bragg and W. L. Bragg (11) developed an X-ray spectrometer which was admirably suited to the investigation of large, well-formed crystals, and introduced a simple method of interpreting the X-ray data so obtained. The structure of a large number of crystals was worked out by this method. The kind of lattice, the actual dimensions, and the nature of the particles forming the lattice were all determined. The X-ray data confirmed the mathematically derived theory of space lattices, and point groups.

As important as these data were, they were, until the powder method was developed, limited to such substances as could be obtained in large, well-formed crystals. The powder method which was developed independently by Hull (12) and by Debye and Scherrer (13), made it possible to investigate the crystalline structure of a substance when it was in the form of a fine powder. This made X-ray methods applicable to the field of theoretical metallurgy. Naturally, the first step was the determination of the structure of pure metals. The principal workers in this field have been Hull, W. L. Bragg and McKeehan. Vegard, Debye, Scherrer, Bohlin, Kirchner, Bijl, Kolkmeijor, and others, have also contributed. A resumé of the work which had been done on the structures of pure metals up to 1922, together with references, has been written by A. W. Hull (14). A more recent (1924) and more complete list has been compiled by Wyckoff (15). Ewald (16) also gives a bibliography of work done on the structure of the elements.

The next step, the investigation of alloys, has little more than been begun, but some generalizations have been reached. Articles giving generalizations and theoretical explanations have been written by Jeffries and Archer (17), Bain (18, 19, 20, 21), Rosenhain (22), Tammann (23), Wever (24), and Davey (25). There is no good bibliography on X-ray investigations of alloys. Most of the alloys and series of alloys other than steel, which have been investigated, together with the names of the investigators, are appended to the bibliography at the end of this report.

There are different modifications of the powder method used

in the investigation of alloys. The Hull method, which is most widely used in this country, has been described by Bain (47), and Davey (48, 49, 25), and Blake (50). The Bohlin method, which was used for a part of the present investigation, was described by Seeman (51), Bohlin (52), Kirchner (30), and Lange (53). An application of the ionization chamber to the powder method has been described by W. H. Bragg (54), and by Owen and Preston (55). A modification of the latter method, which seems to be quite an improvement, has been very recently described by Soller (56).

In addition to the work carried on to determine the crystal lattices characteristic of the elementary metals and alloys, there has been a considerable amount of work done on crystal size and directional crystal orientation in worked and electrolytically deposited metals. Advances in this field prior to 1924 are well presented by Jeffries (78), and references are given to the original papers on the subject. A recent article which also gives references to original papers of other workers has been written by Clark, Brugmann and Heath (79).

Investigations on Steel

The pioneer work on steel was done by Westgren (57, 58, 59, 60) and those who worked with him. In the work reported in 1921 he used two samples of austenitic steel—a nickel steel and a manganese steel. The nickel steel had the following composition:

Nickel	25.2
Carbon	0.24
Manganese	0.50
Silicon	0.10
Phosphorus	0.047
Sulphur	0.010

The manganese steel had the following composition:

Manganese	12.1
Carbon	1.34
Silicon	0.52
Phosphorus	0.10

Both were water-quenched from 1000 degrees Cent. (1832 degrees Fahr.). Sharp lines were obtained which showed that these steels had a face-centered lattice, with 3.58 Angstrom units for the edge of unit cube in the case of the nickel steel, and 3.61 Angstrom units in the case of the manganese steel. An S. K. F.

bearing steel (carbon 1.25 per cent, and other elements not given) was also investigated in the pearlitic and martensitic conditions. No carbide lines were obtained. The annealed steel showed the lines characteristic of alpha iron. The martensitic steel had a body-centered structure with a cube edge of 2.88 Angstrom units. Finally, a hardened high speed steel (composition not given) was also investigated after quenching in oil from 1275 degrees Cent. (2325 degrees Fahr.). There were no gamma iron lines. The lines obtained were from alpha iron (a = 2.86 Angstrom units) and from the iron carbides. Tempering at 575 degrees Cent. (1067 degrees Fahr.) made no difference in the lines obtained.

In 1922 it was shown by Westgren that gamma iron had a different value for edge of unit cube in two samples of austenitic steels. The composition of one was 24.3 per cent nickel, 6.05 per cent manganese, and 1.18 per cent carbon, and the composition of the other was 25.2 per cent nickel and 0.24 per cent carbon. The values of unit cube were 3.64 and 3.56 Angstrom units, respectively. It was also shown that for a straight carbon steel the elementary cube of gamma iron was larger when the quenching was carried out from a higher temperature—1000 and 1100 degrees Cent. were the temperatures used. Work on two different samples also seemed to indicate that there was a change in the alpha iron lattice of the straight carbon steels with different carbon contents—the quantities of the other elements were not given. The result of an investigation of iron-carbide was also reported.

Franz Wever (61) published an article on the crystal structure of steel at about the same time that Westgren published his work, but he published in a journal which is not available, and the following facts concerning his work were obtained from the abstract which appeared in the Physikalische Berichte. For alpha iron, a was found to be 2.850 Angstrom units, and for gamma iron, a was found to be 3.56-3.60 Angstrom units. Cooling austenitic steel in liquid air was found to change part of the gamma iron to alpha iron. Tempering above 300 degrees Cent. was found to convert all of the iron to the alpha form.

Three other points in regard to steel had been published prior to the beginning of the present work. Jeffries and Bain (62) examined a sample of austenitic steel containing 13 per cent manganese and found that it had a face-centered cubic struc-

ture. Andrews (27) found that nonmagnetic nickel steel which had a face-centered cubic structure was partially changed to a body-centered structure by cooling for two hours in liquid air. Bain (63) found that an austenitic nickel steel spontaneously changed, so that after standing fifteen months it gave a pattern of fine-grained ferrite.

During the course of the present investigation, several articles on the structure of steel were published. Zorning (64) investigated a 1.10 per cent carbon steel and reached the following conclusions: Martensite consists of alpha and gamma iron. In troostite, sorbite, and pearlite the iron exists entirely in the alpha form. The gamma iron crystals do not seem to suffer distortion as long as they exist. The alpha iron crystals are probably distorted in martensite, but the distortion decreases as the structure approaches sorbite.

Franz Wever (65, 66, 67) published three articles—one on iron carbide, one on graphite and temper carbon, and one on the constitution of steel. He investigated a series of iron-manganese-carbon alloys. It was found that $a = a_o + 0.00050$ manganese $+$ 0.00645 carbon, where $a_o = 3.578$, and manganese and carbon are expressed in atomic per cents. It was also found that the specific volume $v = 0.1246 + 0.0004$ manganese $+ 0.0041$ carbon. From these data it was calculated that the carbon atoms in austenite are in the interstices of the iron lattice. He also did work on iron-carbon alloys, and concluded that carbon is not soluble in alpha iron under conditions of equilibrium. He concluded that the carbon in martensite is atomically dispersed, and held in the interstices of the alpha iron lattice.

Heindlhofer (68) in his investigation of hardened steel used three samples, compositions of which were given as (1) "carbon-free iron," (2) carbon 0.80 per cent, chromium 0.14 per cent, manganese 0.35 per cent, silicon 0.19 per cent, (3) carbon 1.31 per cent, chromium 0.12 per cent, manganese 0.24 per cent, silicon 0.17 per cent. A spectrometer with an ionization chamber was used. In the two martensitic samples the 3 1 0 planes were found to be closer together than in pure iron and the 2 1 1 planes were found to be farther apart than in pure iron. The difference in the per cent of the carbon made no difference in the positions of the lines. Tempering was found to make the lines more intense. The density of the specimens was determined experi

mentally and compared with the values computed according to different assumptions. He attempted to determine the structure of martensite on the basis of these determinations.

W. E. Williams (69) used both the Laue method and the powder method. The material used was a carbon tool steel (carbon 1.15 per cent, silicon 0.15 per cent, manganese 0.32 per cent, sulphur 0.006 per cent, phosphorus 0.032 per cent, tungsten 0.09 per cent, vanadium 0.05 per cent). A specimen quenched from 1100 degrees Cent. (2012 degrees Fahr.) in water at 10 degrees Cent. gave a Laue pattern which showed asterism. This was considered as an indication that the lattice was warped, or had an exceedingly fine-grained structure. A specimen which was quenched from near the solidus [1320 degrees Cent. (2408 degrees Fahr.)] showed a structure resembling austenite, but gave only alpha iron lines in a position which indicated a cube edge of 2.86 Angstrom units. The effect of tempering was determined by the Laue method. It was found that there was less scattered radiation from the tempered specimen, but that the radial pattern was not altered by tempering. This was considered as an indication that tempering does not produce recrystallization of the distorted crystals, and that the extreme hardness of martensite is not to be ascribed to this distortion.

Soller (56) used a piece of "ordinary commercial steel" in trying out his improved spectrometer. Little concerning steel can be obtained from this article, but it is interesting that there are more peaks than can be accounted for. It is unfortunate that Soller did not use a piece of steel that he knew something about.

Heindlhofer and Wright (70) investigated the effect of tempering hardened steel balls at various temperatures. Two different steels were used: (1) carbon 1.06 per cent, chromium 0.71 per cent, manganese 0.40 per cent, silicon 0.32 per cent, sulphur 0.015 per cent, phosphorus 0.020 per cent; (2) carbon 0.98 per cent, chromium 0.55 per cent, manganese 0.25 per cent, silicon 0.27 per cent, sulphur 0.018 per cent, phosphorus 0.014 per cent. These steels were quenched in water from different temperatures between 800 and 950 degrees Cent., and all showed a martensitic structure. All of the hardened specimens gave gamma iron lines in addition to the alpha iron lines. Different tempering temperatures were used, and the density and X-ray patterns were ob-

tained for each. These results indicated two changes. The first, which is the breaking down of the martensitic structure, is accompanied by an increase in density. The second, which takes place largely between 200 and 260 degrees Cent., is the transformation of the residual austenite, and is accompanied by a decrease in density. The higher the tempering temperature, the more intense were the alpha iron lines obtained.

Mathews (71) gave the results of experiments carried out by Bain, which showed that a larger amount of gamma iron was retained in chromium steel when it was quenched in oil from 830 degrees Cent. (1525 degrees Fahr.) than when it was quenched in water from the same temperature.

Bain (72) determined the temperature at which austenite decomposes for a number of different kinds of steel. Cold work was shown to have an effect similar to that of temperature elevation. Explanations were offered for the results obtained. An explanation was offered for the fact pointed out in the preceding paragraph.

Object of the Research

Westgren's work on iron and steel indicated that there was probably a change in the alpha iron lattice with changes of carbon content. The principal object of this investigation was to determine the effect of carbon content and heat treatment on the space lattice of alpha iron in pure iron-carbon alloys.

Since there seemed to be no agreement among metallurgists concerning the presence of gamma iron in hardened and tempered steels, it seemed to be desirable to determine by the presence of gamma iron lines, whether or not gamma iron was present in the different samples used. It was also the purpose of this work to correlate the X-ray results with the microstructure.

X-Ray Methods Used

On account of the difficulty of preparing suitable steel specimens of a known uniform structure, the Hull method did not prove satisfactory. The method which was used for the oil-quenched specimens was first proposed by Seeman (51), and worked out independently by Bohlin (52). The method which was used for the water-quenched and tempered specimens was suggested by the Seeman wedge spectrograph.

Principle of the Bohlin Method

In the Bohlin method the slit *A*, specimen *B*, and film (ECD) are all placed on the circumference of the same circle (Fig. 1). This means that the surface of the specimen must be curved. All of the rays which come through the slit and are reflected from the same planes, are brought to a focus on the film, because

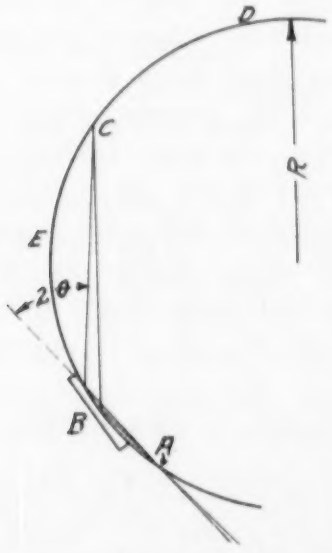


Fig. 1—Sketch Showing Principle of Bohlin Method. Slit, Specimen and Film are all on Circumference of Circle.

equal inscribed angles are subtended by equal arcs. A formula showing the relation between the angle Θ and the distance from the slit *A* to the line on the film (ECD), is easily worked out. The angle ABC = CDA/2R, and 2 Θ is the supplement of angle ABC and is, therefore, equal to ABC/2R. This expression, together with Bragg's formula, $n\lambda = 2d \sin \Theta$, makes it possible to calculate the spacings (d) of the planes of atoms from the locations of the lines, and the wave length (λ) of the X-rays used.

Principle of the Wedge Method

In the Wedge method the edge of a wedge-shaped piece of lead or gold *J* is placed at the center of curvature of the film (OLNM), and the specimen *K* is placed within a few hundredths of a millimeter of the wedge (Fig. 2). The method is similar to the Hull method except that it is the width of the beam of

X-rays which is limited, instead of the size of the sample, and that the edge of the line is measured, instead of an estimated middle, to which a correction must be applied. The knife-edge or wedge extends beyond the specimen, so that the direct beam

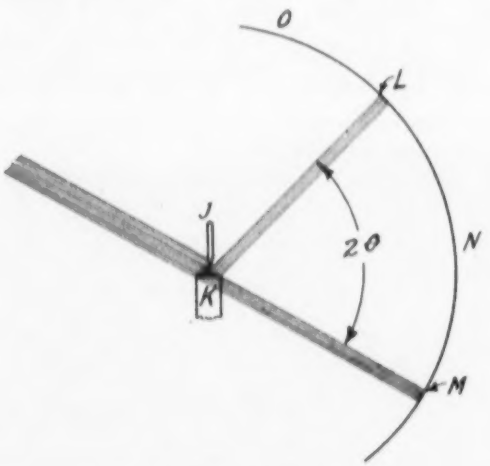


Fig. 2—Sketch Showing Principle of Wedge Method. Edge of Gold Wedge is at Center of Curvature of Film.

of X-rays strikes the film at *M*. Obviously $2\Theta = LNM/R$, and the calculation is, of course, again made by use of the Bragg formula.

Advantages of the Methods Used

Both of the methods used have advantages over the Hull method. The principal advantages arise from the fact that measurements are made to the edges of lines, the positions of which are not affected by the width of the slit, or depth of penetration of the X-rays, into the specimen. Thus these methods avoid the inaccuracies which are due to the size of the specimen and the varying depths of penetration into the specimen, which are inherent in the Hull method. Blake (50) carried out an extensive investigation of these errors in the Hull method, and outlines a procedure by which results can be quite accurately corrected. He discusses a correction proposed by Hadding (73), and suggests that a combination of Hadding's correction and his own would be more satisfactory than either alone. However, it is certainly more satisfactory to avoid the necessity of making such corrections.

The wedge method has the further advantage of making possible a photomicrographic record of the identical surface used for X-ray investigation.

X-Ray Apparatus Used

Bohlin Method

Source of X-Rays. The X-ray tube was a molybdenum target, water-cooled, Coolidge tube manufactured by the General Electric Company for their X-ray diffraction apparatus. The filament was heated by means of three six-volt storage batteries,

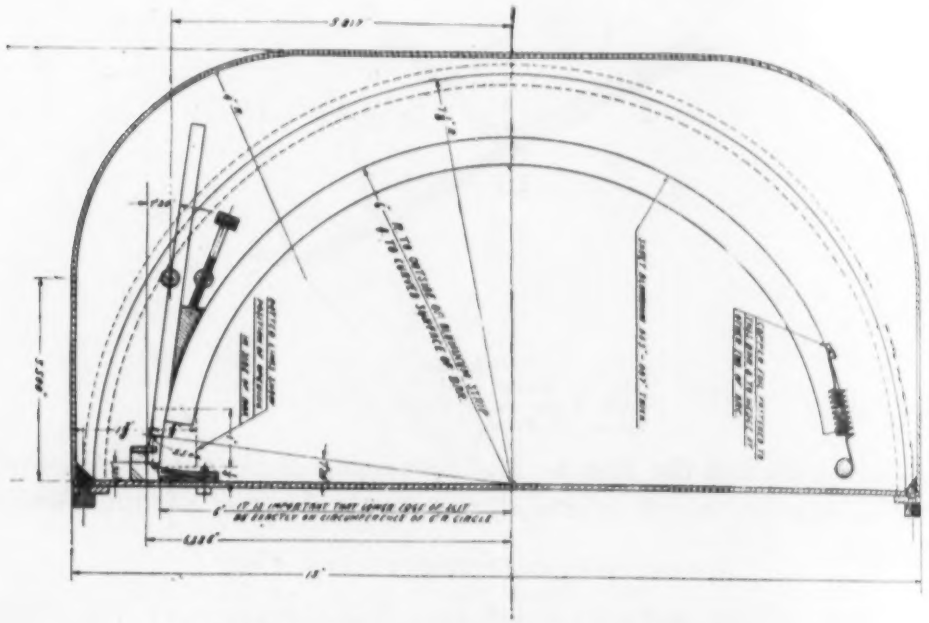


Fig. 3—Sketch of Cassette which was Used for Bohlin Method.

which were connected in series with a slide-wire resistance to control the filament current. The power for the tube was obtained as follows: A 220-volt direct current motor drove a 500-cycle alternating current generator, which was connected to the primary of a transformer. One end of the secondary was grounded, and the other connected to a kenotron. Connection was made from the kenotron to the filament of the tube. The voltage applied to the tube was regulated by means of a variable resistance in the generator field circuit. The tube was placed in a lead-covered box, and the lead, as well as the target of the tube, was grounded.

Cassette. The cassette was designed by the author and made by the Physics Department of the University of Michigan in their shops. The accompanying drawing (Fig. 3) shows the construction of the cassette as it was originally made. The piece of sheet

aluminum was subsequently replaced by a chromium oxide filter, which filtered out more efficiently the secondary iron radiation from the specimen. The cassette holds two specimens side by side—one a standard, and the other the bar under investigation. This was done to eliminate the difficulty due to the absence of a zero on the film, to eliminate the effect of changes due to

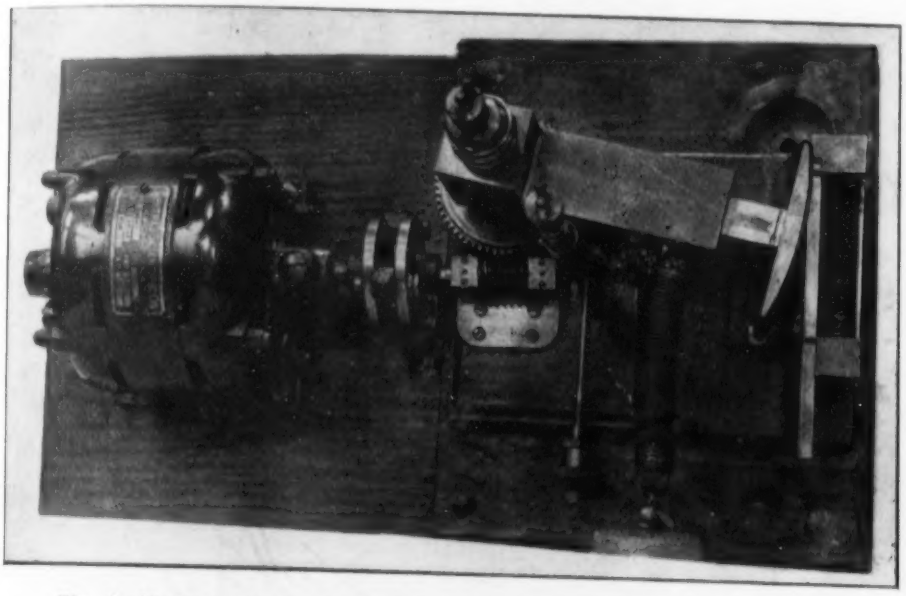


Fig. 4—Machine Used to Grind and Polish Curved Surface on Specimens Examined by Bohlin Method.

development, fixing, washing, and atmospheric conditions, and also to eliminate errors due to inaccuracies in the cassette.

Polishing Machine. It was found that better lines were obtained from a specimen with a polished and etched surface than from one which was merely ground. A polished and etched surface had the further advantage of allowing microscopic examination, although photomicrographs could not be taken on account of the impossibility of bringing all of the field into focus at once.

Consequently, the author designed the polishing machine, which is shown in Fig. 4. The polishing arm is actuated by two cams, one of which produces a lateral oscillation and the other a vertical. The frequency of the lateral oscillation is three times that of the vertical. There are four interchangeable polishing heads,—one covered with emery paper, one with canvas, and two with broadcloth. Three bars could be shaped at once with the emery cloth, and the final polishing done, one bar at a time, with

3F, 10F, and 65F alundum polishing powders, used in the order named on the three cloth covered polishing heads.

Measuring Apparatus

To measure the positions of the lines on the films a millimeter scale was first tried, and later a comparator. Both were

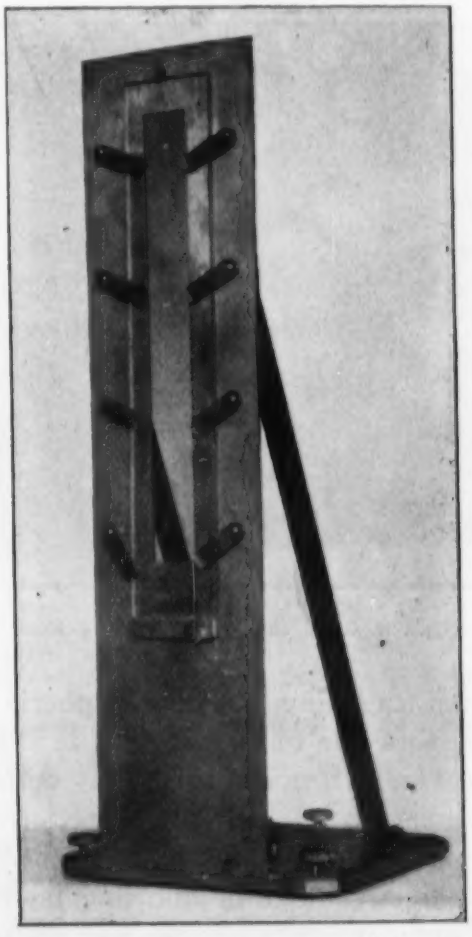


Fig. 5—Film Holder Used for Measuring Positions of Lines.

found to be unsatisfactory. The former was not accurate enough, and the latter magnified the lines too much and did not cover both sides of the film at once. All of the films were remeasured with the arrangement described below, and the values reported in this paper are those so obtained. The films were held vertically against a piece of plate glass in the apparatus shown (Fig. 5). Indirect lighting was used, i. e., light was reflected from a piece of unglazed white paper through the plate glass and the film.

The position of the lines was then determined by means of a cathetometer, which read directly to $^1/_{20}$ millimeter. The space between the film and the cathetometer was completely enclosed by means of heavy black cloth, to obviate the difficulties in measurement which arose when extraneous light was allowed to strike the lens of the cathetometer telescope.

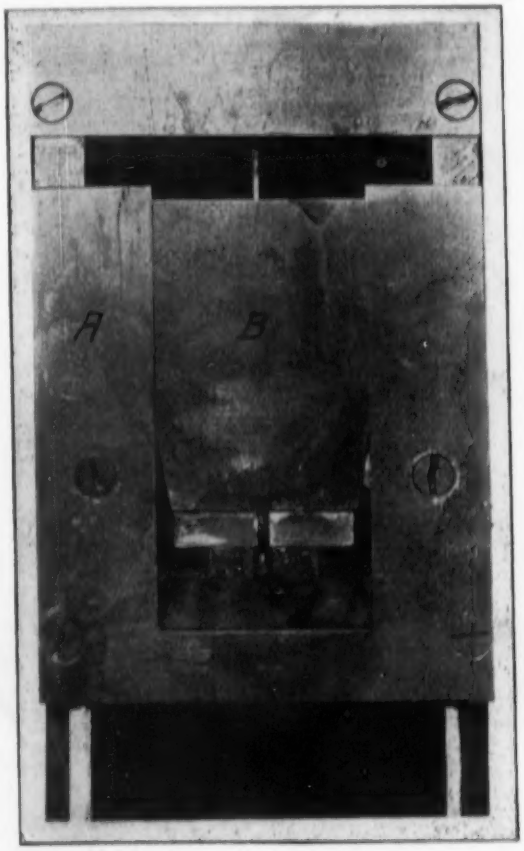


Fig. 6—Specimens and Knife-Edge in Position in Cassette for Wedge Method.

Wedge Method

Source of X-Rays. The apparatus used for the wedge method was an X-ray diffraction apparatus. A detailed description of the apparatus is given in an article by Wheeler P. Davey (48). The outfit is compact and safe. The transformer is enclosed in a sheet metal cylinder, which is grounded. This cylinder is covered by a steel disk having a hole cut in the center, and having 15 radial guides for cassettes. A small metal cylinder which rests on this disk and fits the central hole, acts as a housing for

the tube, and a support for the slit system. The metal plate which covers the small cylinder acts as a support for the molybdenum target, water-cooled, Coolidge tube which is used in the apparatus. The filament is heated by a current induced in a few

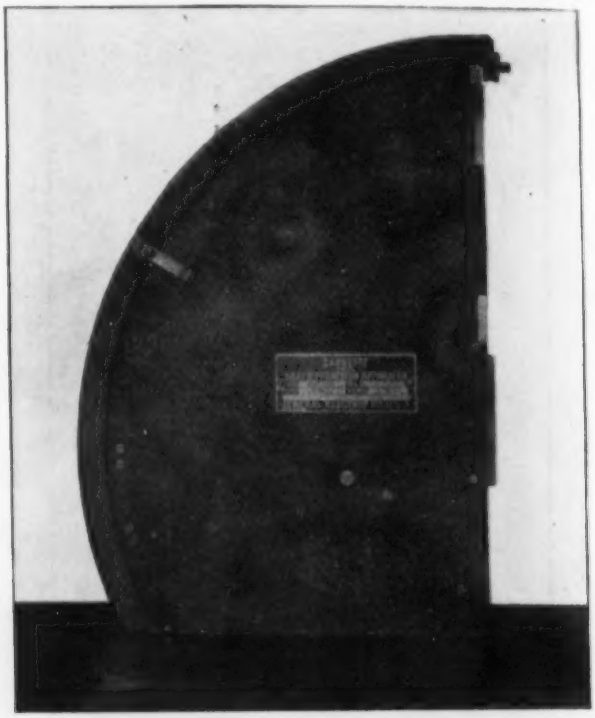


Fig. 7—Wedge Method Cassette.

turns on the high voltage end of the transformer. The tube rectifies its own current.

Cassettes. The cassettes which came with the apparatus were modified, as shown in Figs. 6 and 7. The specimen holders which were originally on the cassettes were removed, and the guide *A* was securely fastened to the front of the cassette with four screws. This guide was so placed that the edge of the gold wedge *B* was held at the center of curvature of the film. While changing specimens, the knife edge was removed and the guide served for part *C*, Fig. 8, which forced the specimens to the proper place.

Filter. In this case the filter used was the zirconium oxide filter, which is built in the cassette. It eliminates the secondary radiation from the specimen quite well, and also greatly reduces the beta doublet.

Measuring Apparatus. The same apparatus was used to measure the films as was used for the other method.

Procedure

Preparation and Treatment of Materials Used

Preparation. During the school year 1922-23, the author, under the direction of Professor E. D. Campbell, worked out a

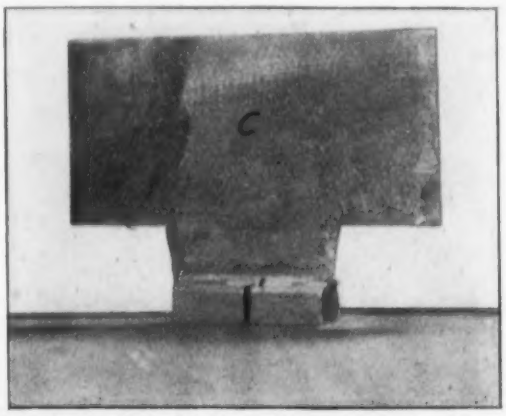


Fig. 8—Piece used to Mount Specimens as Shown in Fig. 6.

method (74) of preparing series of steels varying only in carbon content and having homogeneous structures. Briefly, the method consists in placing bars of different carbon contents, separated from each other, in a furnace at 950 degrees Cent. (1740 degrees Fahr.) in an atmosphere of hydrogen and allowing them to remain there until equilibrium was reached (seven days). The bars used for the oil-quenched specimens were prepared at that time, using bars 15 centimeters long and 6 millimeters square in cross section. The bars used for the water-quenched specimens were 15 centimeters long and 6.3 millimeters in diameter. These bars were prepared in essentially the same manner but with some improvements in technique (76, 77). The square bars were made from material furnished by the American Rolling Mill Company, and the round bars were made from material furnished by the Page Steel and Wire Company. The chemical compositions of the bars are given in Tables I and II, which show the atomic concentration of carbon as well as the per cent by weight.

Treatment of the Bars. The bars listed in Table I were suspended vertically in an electrically heated furnace which had been brought to the temperature from which it was desired to

quench (900 degrees Cent.). After holding at this temperature for one hour, the bars were quenched in oil at 20-30 degrees Cent. The temperature of the bars at the moment of withdrawal from the furnace was measured by means of a standard platinum-platinum-rhodium thermocouple, the bead of which was within

Table I

Atomic Concentration of Carbon and Per Cent by Weight of Bars Tested

IN5 Bar No.	Weight per cent Carbon	Milatoms Carbon per cubic centimeter
11	0.00	0.00
13	0.00	0.00
92	0.11	0.72
18	0.23	1.50
56	0.42	2.75
25	0.60	3.92
87	0.82	5.35
42	0.97	6.34
101	1.03	6.73
104	1.19	7.77
36	1.30	8.49

IN5 bars were made from Armco iron of the following composition:

	per cent		
Carbon	0.015		
Manganese	0.024	Silicon	trace
Phosphorus	0.005	Copper	0.042
Sulphur	0.023	Iron	remainder

2 or 3 millimeters of the bars under treatment. The upper half of the heating chamber in which the bars were suspended, consists of nickel-chromium wire gauze and is surrounded with charcoal, so that the bars may be maintained for any desired length of time without any sign of oxidation.

The bars listed in Table II were sawed nearly through at every centimeter of length, after stamping each section. The bars were heated in the same way as the previous set, but in this case they were heated to 940 degrees Cent., held for 40 minutes, and quenched in water at 2 degrees Cent. These bars were quenched horizontally, so that all sections would be the same. The sections were then broken apart and were tempered as described below.

Sections A were not tempered at all.

Sections B were sealed hermetically in an evacuated pyrex tube which was suspended above water in a round-bottom flask. The flask was fitted with a reflux condenser which was bent in

such a manner that the cold condensate could not strike the tube. The water was then boiled for two weeks continuously.

Sections C were treated in a similar manner. The liquid used in this case was meta cresol. The tube containing the specimens was placed in the liquid on pieces of porous plate, and a ther-

Table II

Atomic Concentration of Carbon and Per Cent by Weight of Bars Tested

OA1 Bar No.	Weight per cent Carbon	Milatoms Carbon per cubic centimeter
232	0.05	0.33
257	0.10	0.65
102	0.21	1.37
161	0.43	2.81
164	0.66	4.31
193	0.90	5.88
74	1.13	7.38
18	1.50	9.80

OA1 bars were made from Armco iron of the following composition:

	per cent		
Carbon	0.010		
Manganese	0.028	Silicon	trace
Phosphorus	0.003	Copper	0.039
Sulphur	0.018	Iron	remainder

mometer placed with the bulb beside it. An air condenser was used in place of the water condenser which was used for sections B. The meta cresol was boiled for five hours. The boiling point was 203 degrees Cent. (400 degrees Fahr.) throughout.

Sections D were similarly tempered for five hours. Benzoic acid was used in this case, and the boiling point was 252 degrees Cent. (485 degrees Fahr.) throughout.

Sections E were heated in a like manner, in boiling glycerine for five hours. The initial boiling point was 284 degrees Cent. (543 degrees Fahr.). During most of the run the boiling point was 285 degrees Cent. (545 degrees Fahr.), but the glycerine gradually decomposed, and the boiling point rose near the end to 287 degrees Cent. (550 degrees Fahr.).

For sections F, mercury was used. The heating was for five hours. The boiling point was 348 degrees Cent. (660 degrees Fahr.) throughout.

Sections G were heated in an evacuated electric furnace to 500 degrees Cent. (932 degrees Fahr.). They were held between 500 and 510 degrees Cent. (932-950 degrees Fahr.) for one hour, and allowed to cool with the furnace.

Sections H were heated in the evacuated electric furnace to 800 degrees Cent. (1472 degrees Fahr.). They were held between 800 and 805 degrees Cent. (1472-1481 degrees Fahr.) for one hour, and allowed to cool with the furnace.

The material used as a standard for the oil-quenched specimens with the Bohlin method, was a decarburized (75) Armco iron bar, which had been oil-quenched from 900 degrees Cent. (1652 degrees Fahr.).

The oil-quenched decarburized Armco iron did not have a sufficiently fine-grained structure for the wedge method. Electrolytic iron furnished by the Bureau of Standards and decarburized (75) was tried and found to have too large a grain. To overcome this difficulty, small pieces of the electrolytic iron were cold-worked by means of a Brinell machine, and heated to 650 degrees Cent. (1202 degrees Fahr.) in an electric crucible furnace. After three such treatments the grain was sufficiently reduced.

Calibration of Thermocouple. The thermocouple, which was a Reichsanstalt standard platinum-platinum-rhodium thermocouple, was checked at the melting point of silver by placing a W-shaped piece of pure silver wire on the bead of the thermocouple, which was covered by a thin layer of asbestos, and then heating slowly in a silica tube furnace with a glass window in the end, until the wire melted. By heating sufficiently slowly, checks were always obtained to within 0.01 millivolt.

Bohlin Method

Specimens. As was shown in the drawing of the cassette and in the photograph of the polishing machine, the full length bars (15 centimeters long) were used as specimens. Three of these bars were clamped in the polishing machine, and ground down with emery cloth. The bars were then polished one at a time. With a little practice, the bars could be taken down to the correct dimension and at the same time get a surface which had only a few light scratches. The curved surface was etched with 4 per cent alcoholic solution of nitric acid. The surface so prepared was satisfactory for X-ray examination, and was examined under the microscope.

Imperfections in the Cassette. There was found to be a great deal of general blackening on the film, due to secondary

rays from the back of the cassette. After discovering the cause of the blackening, the difficulty was easily remedied by placing a piece of lead foil between the copper foil and the back of the cassette.

The most troublesome defect was some inaccuracy in the parts which determined the location of the specimens, consequently the lines obtained were blurred when most of the curved surface of the specimen was used. Moreover, the two sides of the cassette were not the same. By using only two millimeters of the specimen, sharp lines were obtained.

To eliminate errors due to the inaccuracies in the cassette, and to obtain sharp lines, the following procedure was adopted and used for all work done by this method. The holder for the cassette was so adjusted that a length of about 2 millimeters at the middle of the polished arc was irradiated. The cassette was held in exactly the same position for all exposures. The cassette was calibrated by taking identical standard bars, and making several exposures with the bars in one position for half the exposure and interchanged for the other half. All of the films so obtained were identical and gave a calibration for the cassette.

Exposures. The first exposures were all made with 35 kilovolts across the tube, and 30 milliamperes of current. The length of exposure necessary to get the gamma iron lines to appear from oil-quenched specimens was at least thirty hours, and forty hours was found to be a more satisfactory exposure. When the General Electric Company diffraction apparatus was substituted, a holder was made so that the Bohlin cassette could be placed on that outfit. The current through the tube was 25 milliamperes and an exposure of 48 hours was used.

Films. Duplitized superspeed X-ray films were used. They were developed with X-ray developer and then fixed, washed and dried in the ordinary way. After drying, the emulsion on the back side was removed with a rubber policeman and nitric acid, which had been diluted with an equal volume of water. The film was then rinsed and dried.

Measurements. In measuring the positions of the lines on the films, the cathetometer and film holder were both set perpendicularly and the setting was checked by the use of a plumb-bob. The film was adjusted in the holder so that the film was

parallel to the cathetometer. This condition was determined by setting the vertical cross hair on the edge of the darkened portion of the film, and noting that it stayed there while the telescope was raised and lowered. The cross hairs in the cathetometer telescope were so adjusted that the vertical cross hair appeared to coincide with a thread which was used as a plumb line. When everything was in adjustment, the positions of the lines were read. The edge of the line farthest from the zero was measured in every case. For each line the intensity of the illumination was varied until the edge of that line could be most easily detected. Several readings were then taken on each line, and the average of the readings is the value used. It was found that the readings could be made more accurately in a darkened room, so that all except the first few were so made.

Calculation of Results. The calculation of the fractional change in the side of unit cube a was carried out by substituting in the equation

$$\frac{\triangle a}{a} = - \triangle \Theta \sqrt{\frac{K^2 a^2}{\lambda^2} - 1}$$

which was obtained by differentiating the Bragg equation

$$\lambda = Ka \sin \Theta$$

and substituting the finite increments $\triangle a$ and $\triangle \Theta$ for the differentials da and $d\Theta$. This calculation obviously does not require the presence of a zero point to measure from. Heindlhofer (68) used this method of calculating the change in a. The calculation of the side of unit cube is a different matter, and an approximation can be had either by measuring the distance between the two lines, or the positions of the lines can be determined by comparison with lines from material of known crystal structure. The formula to be used in the former case is:

$$\cot \frac{L_1}{4R} = \frac{\frac{d_1}{d_2} - \cos \frac{a}{4R}}{\sin \frac{a}{4R}}$$

where L_1 is the distance from the slit to the line nearer the slit, R is the radius of curvature of the film,

$$\frac{d_1}{d_2}$$

the ratio of the spacings of the atomic planes involved, which can be calculated from the indices, and a is the measured distance between the lines. This equation was derived by dividing the Bragg equation for one line by that for the other, and solving for

$$\frac{L_1}{4R}.$$

The value of the side of unit cube calculated in this manner is not very accurate, for the inaccuracies in the cassette and changes in the film are not corrected or eliminated in any way. Moreover, the distance measured is relatively short, and a small absolute error is a larger percentage error than if the measurement could be made from the slit. However, such a calculation will give a close approximation. Kirchner (30) used this method in calculating part of his results.

The Wedge Method

The procedure which had to be followed in the Bohlin method, on account of the inaccuracies in the cassette, sacrificed two of the advantages of the method,—short exposures, and the use of specimens with coarse crystal grains. Moreover, to be compelled to always use the cassette in exactly the same position and calibrate it for that position, could not be considered entirely satisfactory. The preparation of the specimens was a slow process, and after they were prepared, photomicrographs could not be taken.

In view of these facts, the wedge method, which had not previously occurred to the author, was adopted. This method was quite satisfactory, except that the crystal grains had to be still finer than for the Bohlin method as it was used in this work.

Specimens. As was described in the preparation and treatment of the materials, the specimens used for the wedge method were 6.3 millimeters in diameter and 1 centimeter long. One end of the specimen was ground down 0.5 to 1.0 millimeters to avoid any surface change which might have occurred at the saw cut. That end was then polished on polishing discs, using 3F, 10F, and 65F alundum polishing powders. The specimens were etched with 4 per cent alcoholic solution of nitric acid, and photomicrographs were made.

Mounting the Specimens. The specimens were mounted in the cassette as shown (Fig. 6). First, modeling clay was placed at the front of the cassette and the specimen placed in it at approximately the correct place. The specimens were then forced into the clay by means of the piece C shown in Fig. 8. This piece was allowed to remain in place for a few minutes, to avoid having the clay force the specimens up a little when it was removed. The knife-edge *B* was then put in place and the exposure started.

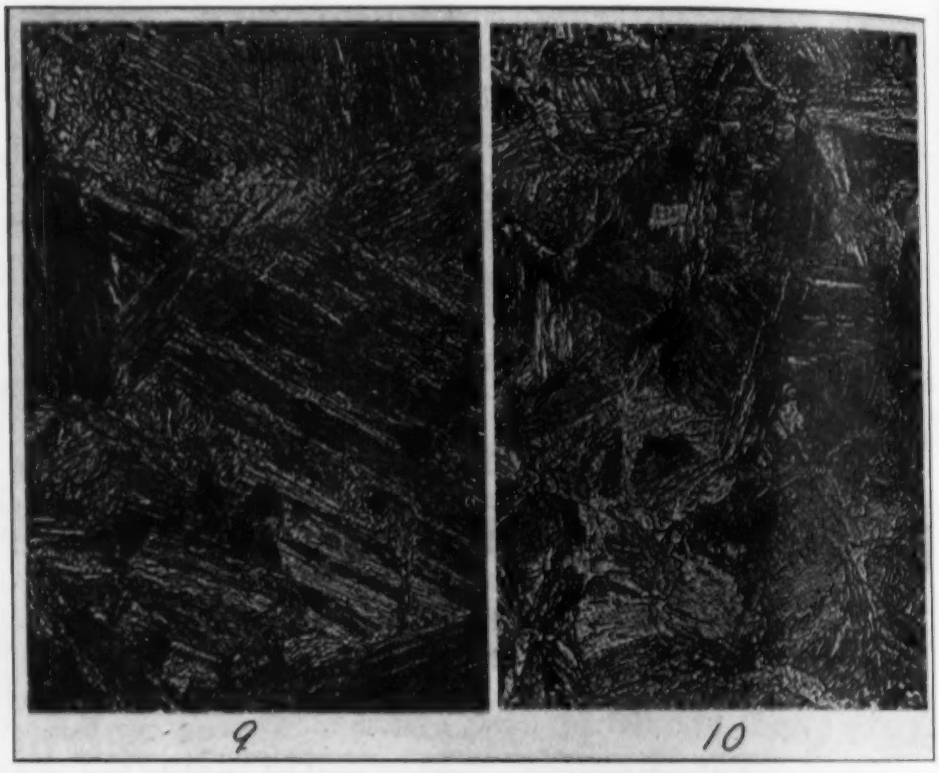


Fig. 9—Photomicrograph of Small Specimen of 0.05 Per Cent Carbon Steel Quenched in Large Volume of Ice Water. Fig. 10—Photomicrograph of Small Specimen of 0.10 Per Cent Carbon Steel Quenched in Large Volume of Ice Water. Specimens Etched with 4 Per Cent Alcoholic Solution of Nitric Acid. Magnification 500X.

Exposures, Development and Measurement. The exposures, development and measurement of the films were carried out in a manner identical with that for the Bohlin method, except that no emulsion was removed from the film, because the paths of the X-rays were normal to the film.

Calculation. The calculations were carried out in essentially the same manner as for the Bohlin method. In this method, however, the angle between the original beam and the diffracted beam is a central angle and, consequently, $2\Theta = D/R$, where

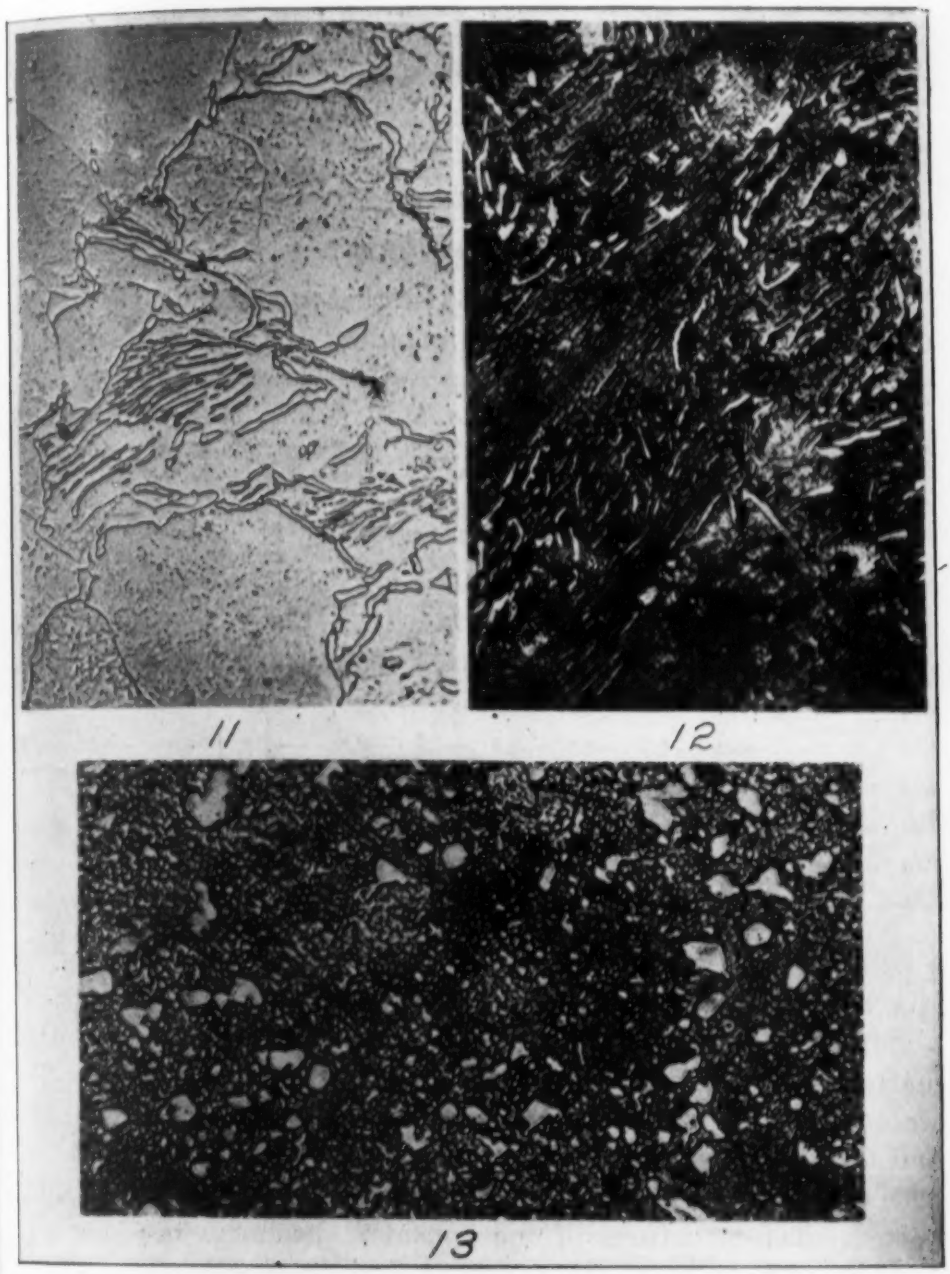


Fig. 11—Photomicrograph of 0.43 Per Cent Carbon Steel Annealed and Etched with a 4 Per Cent Alcoholic Solution of Nitric Acid. Magnification 500X. Fig. 12—Photomicrograph of 0.90 Per Cent Carbon Steel Annealed and Etched with 4 Per Cent Alcoholic Solution of Nitric Acid. Magnification 500X. Fig. 13—Photomicrograph of 1.13 Per Cent Carbon Steel Annealed and Etched with 4 Per Cent Alcoholic Solution of Nitric Acid. Magnification 500X.

D is the distance from the intersection of the direct beam with the film to the line. The spacing of the planes which give rise to a given line can be read directly by means of the scale which was furnished with the X-ray diffraction apparatus. The cor-

rections necessary to compensate for the changes in the length of the film can be determined from the standard lines. This procedure was used in determining the side of unit cube of gamma iron, and in identifying other lines.

Results

Microstructures

Microscopic examination showed that the oil-quenched specimens were troostitic up to and including the 0.42 per cent carbon specimen. All specimens of higher carbon content showed a mixture of martensite and troostite. The largest amount of martensite was found in the 0.97 per cent carbon specimen. The water-quenched specimens were all martensitic—even the 0.05 and 0.10 per cent carbon specimens, as shown in Figs. 9 and 10. The structures of the tempered specimens are what would be expected. The structures of the annealed specimens are shown in Figs. 11, 12, 13.

Table III

Measured Shift in the Alpha Iron Lines and the Calculated Per Cent

Carbon Content per cent	Treatment	Displacement lines in millimeters					Per cent changes in a				
		1 1 0	2 0 0	2 1 1	2 2 0	3 1 0	1 1 0	2 0 0	2 1 1	2 2 0	3 1 0
0.43	water-quenched	0.0	0.0	+0.1	+0.2	+0.4	0.0	0.0	+0.08	+0.13	+0.23
0.66	water-quenched	+0.1	—0.4	+0.2	+0.4	—0.7	+0.14	—0.39	+0.16	+0.26	—0.40
0.90	water-quenched	+0.1	—0.6	+0.3	....	—0.2	+0.14	—0.58	+0.23	.....	—0.12
1.13	water-quenched	....	—0.4	+0.3	—0.2	—0.2	.....	—0.39	+0.23	—0.13	—0.12
1.50	water-quenched	—0.2	—0.3	—0.1	—0.4	—0.5	—0.28	—0.29	—0.08	—0.26	—0.29
0.43	tempered at 100 C.	0.0	0.0	+0.1	+0.2	+0.4	0.0	0.0	+0.08	+0.13	+0.23
0.90	tempered at 100 C.	....	—0.2	+0.2	+0.2	—0.2	.....	—0.20	+0.16	+0.13	—0.11
1.13	tempered at 100 C.	....	—0.3	....	+0.3	—0.2	.....	—0.29	.....	+0.29	—0.11

The + sign indicates an increased interplaner distance.
The — sign indicates a decreased interplaner distance.

X-Ray Results

Table III shows the measured shift in the alpha iron lines and the calculated per cent. Change in *a* for the water-quenched and the tempered specimens. The specimens not listed gave lines which were identical in position with those from the electrolytic iron standard. The oil-quenched bars all gave lines which were identical in position with those from the standard bar. Table

Table IV

Measured Gamma Iron Lines and Calculated Values of (a)

Carbon Content per cent	Treatment	Values of a calculated from lines		
		2 0 0	2 2 0	3 1 1
	Degrees Cent.			
1.19	oil-quenched	3.56	3.56	
1.30	oil-quenched	3.56	3.56	
.90	water-quenched	3.590	3.586	3.605
1.13	water-quenched	3.610	3.615	3.605
1.50	water-quenched	3.612	3.598	3.608
.90	Tempered at 100	3.590	3.586	3.599
1.13	Tempered at 100	3.620	3.605	3.605

Table V

First Line Resolved

Carbon Content per cent	Treatment Degrees Cent.	First line resolved
0.11	oil-quenched	2 0 0
0.23	oil-quenched	2 2 0
0.42	oil-quenched	3 2 1
0.05	water-quenched	2 1 1
0.10	water-quenched	2 2 0
0.21	water-quenched	3 2 1
0.43	tempered at 203	3 3 2
0.43	tempered at 252	2 2 0
0.43	tempered at 285	2 1 1
0.43	tempered at 348	2 1 1
0.43	tempered at 500	2 1 1
0.43	annealed at 800	2 0 0
0.90	tempered at 252	3 2 1
0.90	tempered at 285	2 2 0
0.90	tempered at 348	2 1 1
0.90	tempered at 500	2 1 1
0.90	annealed at 800	2 0 0
1.13	tempered at 285	3 2 1
1.13	tempered at 348	2 1 1
1.13	tempered at 500	2 1 1
1.13	annealed at 800	2 0 0

IV shows the gamma iron lines which were intense enough to measure and the value of a calculated from each.

Table V gives the first line which was resolved, and where a sample is not listed, none of the lines were resolved. In explanation of this table, the X-rays used were not monochromatic, but consisted largely of the charasteristic K-radiation of molybdenum, which is composed of four different wave lengths--α_1 (.708 Angstrom units), α_2 (.712 Angstrom units), β_1 (.631 Angstrom units), β_2 (.619 Angstrom units). The zirconium fil-

ter in the cassette absorbs most of the beta lines, although on some of the films the Kβ lines are present. The lines given in the tables are due to the two Kα rays (the alpha doublet). The wave lengths are close together and with well formed uniform grains they produce two lines close together, i. e., the doublet is resolved. Nonuniformity or distortion within the crystal grains causes these two lines to widen and merge, i. e., the doublet is not resolved.

There are two points not included in the tables which are important. The first is that 1.13 per cent carbon steel specimens tempered at 500 degrees Cent. (932 degrees Fahr.) and annealed at 800 degrees Cent. (1472 degrees Fahr.) gave a large number of iron carbide lines. No other films showed any carbide lines.

The other result which was not included in the tables was the appearance of new lines corresponding to a body-centered tetragonal lattice. The 0.90 per cent carbon water-quenched specimen gave 211 and 110 lines which were widened considerably on the short wave length side. The 1.13 per cent carbon water-quenched specimen showed this widening on all of the lines, but the 1.13 per cent carbon specimen tempered at 100 degrees Cent. (212 degrees Fahr.) did not. The 1.50 per cent carbon specimen showed new lines which corresponded to a body-centered tetragonal lattice having an axial ratio of 1.06. These lines were at approximately the same position as the short wave length edge of the excessively wide lines just mentioned.

Discussion of Results

A point to be kept in mind in considering the results obtained is that all measurements are made to the long wave length edge of the lines. Therefore, if the lattice were not uniform throughout the specimen, the measurements would give the dimensions of those regions which have the smallest interplaner spacings, and those regions which have a greater spacing would simply cause the line to widen out on the short wave length side. Moreover, if the material consisted of lattices of different sizes, and a relatively small amount of the smallest one was present, the edge to be measured would be faint and difficult to measure.

Oil-Quenched Specimens

The characteristics of the lines were those which it has just been pointed out would exist if the lattice were not uniform. The

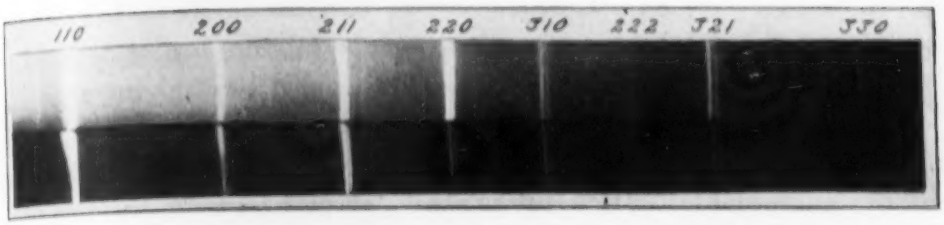


Fig. 14—X-Ray Pattern from 1.13 Per Cent Carbon Steel Annealed. Upper Lines Are from Electrolytic Iron Standard. Unidentified Lines Are Due to Kβ Rays. The Lower Lines Are Due to the Steel. The Many Faint Lines Are Due to the Carbides.

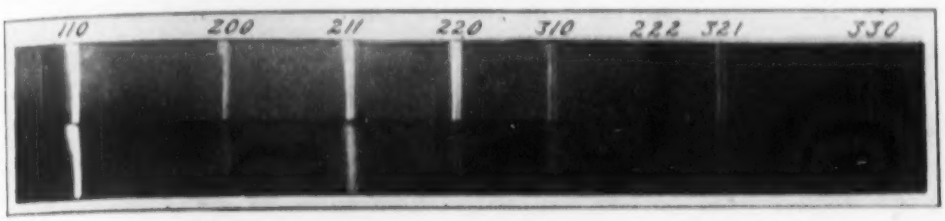


Fig. 15—X-Ray from 1.13 Per Cent Carbon Steel Tempered at 203 Degrees Cent. Upper Lines Are from Electrolytic Iron Standard. The Lower Lines Are from the Steel. Note the Absence of Resolution of the Lines, and Absence of Gamma Iron Lines.

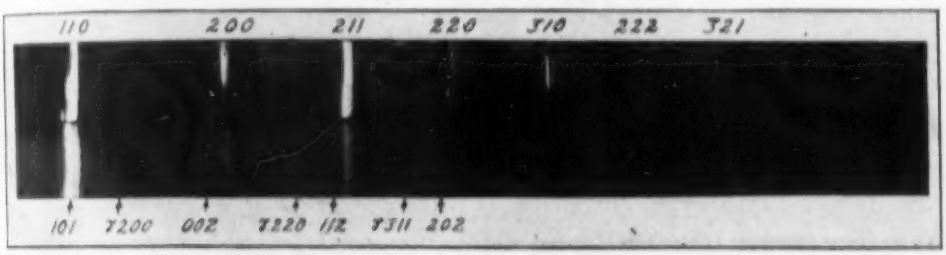


Fig 16—X-Ray Pattern from 1.30 Per Cent Carbon Steel Quenched from 950 Degrees Cent. in Ice Water. Upper Lines Are from Electrolytic Iron Standard. Unidentified Lines Are Partly Due to the Kβ Rays, and Partly Due to Surface Changes of Specimen which Were Eliminated by Repolishing. The Lower Lines Due to the Steel Are Partly Alpha Iron Lines as Are Those of the Standard, Partly Gamma Iron Lines as Indicated, and Partly Due to a Body-Centered Tetragonal Lattice, Having an Axial Ratio of 1.06.

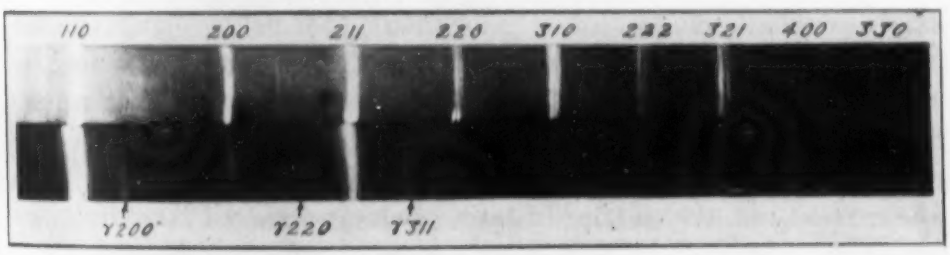


Fig. 17—X-Ray Pattern from 1.13 Per Cent Carbon Steel Quenched from 950 Degrees Cent. in Ice Water. Upper Lines Are from Electrolytic Iron Standard. Note Broad Lines from Steel Which Correspond to Body-Centered Tetragonal Lattices Having Axial Ratios All the Way Between 1.06 and 1 (Body-Centered Cubic).

locations of the lines were the same within experimental error for all of the steels of this series and decarburized ingot iron. This would indicate that some of the lattice at least was the same as that of pure alpha iron. The fact that the lines widened out

on the short wave length side seems to be most easily and logically explained by assuming that some parts of the lattice were dilated. The greater the broadening, the more lines there were in which the doublets have merged into one line. Therefore, the number of lines not resolved serves as a rather delicate indicator of the amount of dilation up to 0.60 per cent carbon, where none of the lines were resolved. Above that, the intensity and definition of the lines give an indication of the extent of the dilation. Other factors, such as mechanical strains, and a fine crystalline structure, may enter into the problem, but they are probably minor factors, or the lines would widen out on both sides.

Gamma iron lines did not appear until the carbon content had reached 0.97 per cent, and they were quite weak even for the specimens with higher carbon contents. The value of *a* for gamma iron in these specimens was found to be 3.56 Angstrom units. Although this determination by the Bohlin method with such weak lines was in all probability not as accurate as the ones made by the wedge method, it was certainly accurate enough to show that the lattice did not have the same dimensions in the oil-quenched and the water-quenched specimens.

Water-Quenched Specimens

For the 0.05, 0.10, and 0.21 per cent carbon specimens the results indicated that part of the lattice still had the same dimensions as that of pure iron. With increasing amounts of carbon, the per cent of the lattice which possessed the same dimensions as that of pure iron became less and less, and, consequently, the edge to which measurement was made became less and less distinct. In the 0.43 per cent carbon specimen there was none, or only little of the lattice of the original dimensions. Consequently, measurement showed the lines to be in slightly different positions. The shift of the line is then a criterion by which to judge the extent of the lattice dilation when none of the lines are resolved. There are, however, certain disturbing factors.

The specimens with 0.66 per cent or more of carbon contained gamma iron. For the 0.90 per cent carbon steels, both water-quenched and tempered at 100 degrees Cent., the median of the values obtained for the length of the side of unit cube was 3.59 Angstrom units (see results). The lattice dimensions seemed to be larger and nearly constant for the two water-quenched speci-

mens of higher carbon content, as well as for the 1.13 per cent carbon specimen tempered at 100 degrees Cent. The median of the values obtained was 3.608 Angstrom units.

This would mean that the spacings of the 4 0 0 planes would be 0.898 to 0.903 Angstrom units, whereas the 3 1 0 planes of electrolytic iron were found to have a spacing of 0.905 Angstrom units. In other words, as soon as the 4 0 0 line became intense enough to see, it made the 3 1 0 line appear to be at too great an angle, and indicated a contraction in the alpha iron lattice which did not exist. There is, however, a more serious difficulty in interpreting the changes in the positions of the alpha iron lines.

As was stated in the descriptions of the films, the lines on the film obtained from the 1.50 per cent carbon specimen could be accounted for by the presence of a body-centered tetragonal lattice with a value of a about 0.28 per cent smaller than that of alpha iron, and a value of c 1.06 times that of a. This would mean that as soon as any line from this lattice is intense enough to be seen, the corresponding line of the alpha iron pattern will seem to indicate a contraction in the alpha iron lattice. This explains the fact that the 2 0 0 and 3 1 0 lines are displaced to the long wave length side with the 0.66-0.90 per cent carbon specimens, and the 2 0 0, 2 2 0, and 3 1 0 lines are displaced in that direction with the 1.13 per cent carbon steel. In the case of the 3 1 0 lines, there are two factors, so that even though both are weak, the effect is noticeable.

It should be borne in mind that all the specimens of this series are martensitic and that the changes in the X-ray patterns are, therefore, due to the amount of carbon present in the same metallographic constituent. As the carbon content increased, the following changes took place in the iron lattice. At first there was a dilation of a part of the body-centered alpha iron lattice. Then the part of the lattice which was dilated, as well as the extent of the dilation, gradually increased. Finally, no noticeable quantity of the alpha iron lattice remained undilated. Further increase in carbon content caused the retention of part of the iron in the gamma form (face-centered cubic lattice), and probably a further dilation of alpha iron. Shortly after this, a new lattice made its appearance—the body-centered tetragonal lattice previously mentioned. The gamma iron lattice was also

somewhat dilated. Further increase in the carbon content increased the amounts of this body-centered tetragonal lattice. The body-centered tetragonal lattice did not seem to be of uniform dimensions in the 0.90 and 1.13 per cent carbon specimens, but did seem to be quite uniform in the case of the 1.50 per cent carbon specimen.

Tempered Series

Since the tempering process has the effect of agglomerating the carbides, it would be expected that on tempering, the changes described above would take place in the reverse sense. This is exactly what did take place. Tempering at 100 degrees Cent. caused a disappearance of almost all of the last component to make its appearance—the body-centered tetragonal lattice. Tempering at 203 degrees Cent. caused the disappearance of all the gamma iron lines, except in the case of the 1.13 per cent carbon steel, where they were quite faint; and also caused some of the alpha iron lattice to assume the dimensions of the lattice of pure iron. Higher tempering temperatures caused more and more of the lattice to return to the dimensions of a pure iron lattice. The lower the total carbon, the more complete the change at a given temperature. Specimens *E* tempered at 285 degrees Cent. bring out this point clearly. With 1.13 per cent carbon steel, the 3 2 1 line was the first to be resolved, while the 0.90 per cent carbon specimen showed partial resolution of the 2 1 1 line, and the 0.43 per cent carbon specimen gave good resolution of the 2 1 1 line. It was only on the annealed specimens that the effect of the carbides on the alpha iron lattice was completely eliminated.

An interesting and not easily explained fact is that iron carbides do not give any carbide lines when they are precipitated in sufficiently large particles to be easily seen at 500 diameters magnification. Even the annealed specimens with 0.43 and 0.90 per cent carbon did not give strong enough lines to enable one to state definitely that they existed. The 1.13 per cent carbon specimen did give carbide lines, but they were weak. It may be that longer annealing, or annealing at a higher temperature, would cause these lines to appear on the films from the other specimens.

The results obtained for the tempered specimens assist in explaining the results obtained for the oil-quenched specimens. The results obtained for the oil-quenched specimens were the same as would be expected from specimens which had been water-

quenched and tempered at a temperature a little lower than 200 degrees Cent. The relatively slow cooling during oil quenching would account for such results.

Possible Explanations of Previously Observed Facts

W. E. Williams (69) makes an interesting statement in regard to a steel quenched from 1320 degrees Cent. (2408 degrees Fahr.). "The structure is a cube-centered lattice, the cube side being 2.86 Angstrom units. There was no trace of any face-centered lattice lines. The steel thus, despite its appearance under the microscope, is in the alpha state." The steel under consideration was of the following composition: carbon 1.15 per cent, silicon 0.15 per cent, manganese 0.32 per cent, sulphur 0.006 per cent, phosphorus 0.032 per cent, tungsten 0.09 per cent, vanadium 0.05 per cent. It does not seem likely that after quenching such a steel from 1320 degrees Cent. (2408 degrees Fahr.) the iron would all be in the alpha state. Extending the results which have just been presented, it would seem that such a treatment might produce large amounts of the body-centered tetragonal structure. Considering the fact that the method used by Williams brought only one line into focus and gave diffuse lines for the others, he may have obtained a single broad line in place of each pair of lines which should have been obtained if all the structure had been body-centered tetragonal.

The author, while working for his master's degree, found that the modulus of elasticity of steel was lowered by drastic quenching, and that it was then raised considerably by tempering at 100 degrees Cent. This can now be explained by the appearance and disappearance of the body-centered tetragonal lattice.

The improvements in other physical properties caused by tempering at 100 degrees Cent. may be due in a large measure to the disappearance of the body-centered tetragonal lattice.

Future Work Indicated by Results

It seems that an investigation of high carbon pure iron-carbon alloys quenched at various temperatures between the A_1 point and the solidus, should give much information concerning the structure of steel and the changes which take place during heat treatments.

Work similar to that described in this thesis, but using series

of steels with different alloying materials in each series, should give much information concerning the effect of these elements on the structure of alloy steels, and help to interpret and predict their properties.

It would also be interesting to get diffraction patterns from steel at different temperatures, and thus determine whether the body-centered tetragonal lattice is a stable structure at any temperature, or whether it is a metastable transition structure which is encountered only in quenched steel. Such an investigation should bring out other important data.

Conclusions

The conclusions which were reached as a result of this investigation of pure iron-carbon alloys are summarized below.

1. Changes in the dimensions of the minimum alpha iron lattice (body-centered cubic) which take place during heat treatments are small (0-0.3 per cent approximately) and are a function of the carbon content and heat treatment. The side of unit cube increases slightly as the carbon content increases, but the change is not uniform throughout the lattice.

2. The gamma iron lattice (face-centered cubic) also changes with carbon content and heat treatment. The higher the carbon content and the more drastic the quench, the larger the size of unit cube. The range of values of a encountered in this work was from about 3.56 to 3.608 Angstrom units.

3. With drastic quenching of eutectoid and hypereutectoid steels, there is formed a crystal structure which has not been previously described, and which seems to be a body-centered tetragonal structure. The body-centered tetragonal lattice is not uniform with the lower carbon contents, but with higher carbon contents the lattice becomes fairly uniform. With the 1.50 per cent carbon specimen the value of a was 2.85 Angstrom units and the value of c was 3.02 Angstrom units.

4. The body-centered tetragonal lattice is less stable at low temperatures than the gamma iron lattice. The body-centered tetragonal lattice disappears on tempering at 100 degrees Cent., while the gamma iron does not disappear until 200 degrees Cent. is reached, and in the case of the 1.50 per cent carbon specimen it had not entirely disappeared then.

5. The relative quantities of the three kinds of lattices which

are produced by quenching are functions of the carbon content and the rate of cooling.

6. Carbides, for some unknown reason, do not in general give lines on the film. By annealing the high carbon steels, carbide lines are obtained. Thorough annealing or spheroidization might cause them to appear with lower carbon contents.

Acknowledgment

The author heartily thanks the General Electric Company for the two-year tenure of a Charles A. Coffin Fellowship which made this research possible.

Investigations on Alloys Other Than Steel*

Iridosmium	Aminoff and Phragmen (26)
Iron-nickel	Andrews (27)
Iron-cobalt	Andrews (27)
Copper-zinc	Andrews (27)
Cu_2Zn_3	Beeker and Ebert (28)
Mg_4Al_3	Beeker and Ebert (28)
NiAl	Beeker and Ebert (28)
$CuAl_2$	Beeker and Ebert (28)
CuAl	Beeker and Ebert (28)
Ni_6W	Beeker and Ebert (28)
Cu_9Al	Beeker and Ebert (28)
Copper-aluminum	Jette, Phragmen, and Westgren (29)
Copper-gold	Kirchner (30)
Copper-nickel	Lange (31)
Copper-gold	Lange (31)
Silver-palladium	McKeehan (32)
Silver-gold	McKeehan (32)
Palladium-hydrogen	McKeehan (33)
Palladium-hydrogen	McKeehan (34)
Palladium-hydrogen	Yamada (35)
Iron-nickel	McKeehan (36)
Copper-zinc	Owen and Preston (37)
Copper-aluminum	Owen and Preston (38)
Aluminum-magnesium	Owen and Preston (38)
Copper-nickel	Owen and Preston (38)
Iron-silicon	Phragmen (39)
Copper-nickel	Sacklowski (40)
Tungsten-molybdenum	Van Arkel (41)
Silver-gold	Van Arkel (41)
Copper-aluminum	Westgren and Phragmen (42)
Copper-zinc	Westgren and Phragmen
Copper-zinc	Westgren (43) and Westgren and Phragmen (44)
Copper-aluminum	Westgren (43) and Westgren and Phragmen (44)
Silver-zinc	Westgren (43) and Westgren and Phragmen (44)
Silver-cadmium	Westgren (43) and Westgren and Phragmen (44)
Gold-zinc	Westgren (43) and Westgren and Phragmen (44)
Silver-tin	Westgren (43) and Westgren and Phragmen (44)
Silver-aluminum	Westgren (43) and Westgren and Phragmen (44)
Heusler-alloys	Young (45)

*The figures in brackets have reference to the figures to the list of references which follows:

Zinc-aluminum	Phebus and Blake (46)
Lead-tin	Phebus and Blake (46)
Chromium and Nickel	Phebus and Blake (46)
Aluminum-nickel	Phebus and Blake (46)

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Discussion of Paper

E. C. BAIN: I would compliment Dr. Fink upon the excellent X-ray patterns which he has made from which to compute the atomic spacings in martensite. In order to amplify what he has said and perhaps to make it more clear what the significance of the work is, I beg to repeat what I have offered before in lectures.

In the first place gamma iron solid solutions are a face-centered cubic arrangement of atoms with cube edge 3.60 Angstrom units in length. Such a cubic arrangement is at once a tetragonal body-centered arrangement of atoms with the base edge 2.54 Angstrom units in length and the vertical edge 3.60 Angstrom units in height. Or, as is usually designated, body-centered tetragonal with axial ratio 1.414 ($\sqrt{2}$). Now alpha iron is body-centered cubic with base edge 2.86 Angstrom units in length. The process, then, of the allotropic change so far as crystal structure is concerned, is merely the flattening or upsetting of the space lattice from 3.60 Angstrom units to 2.86 Angstrom units in height and the resulting widening of the unit crystal base to 2.86 Angstrom units from 2.54 Angstrom units. In such a process, as may be seen in this figure, the tetragonal axial ratio is changed from 1.414 to unity. (Fig. 1).

But let us assume that the forces which bring about this change in atomic spacing when the iron or steel is cooled below the transformation temperature

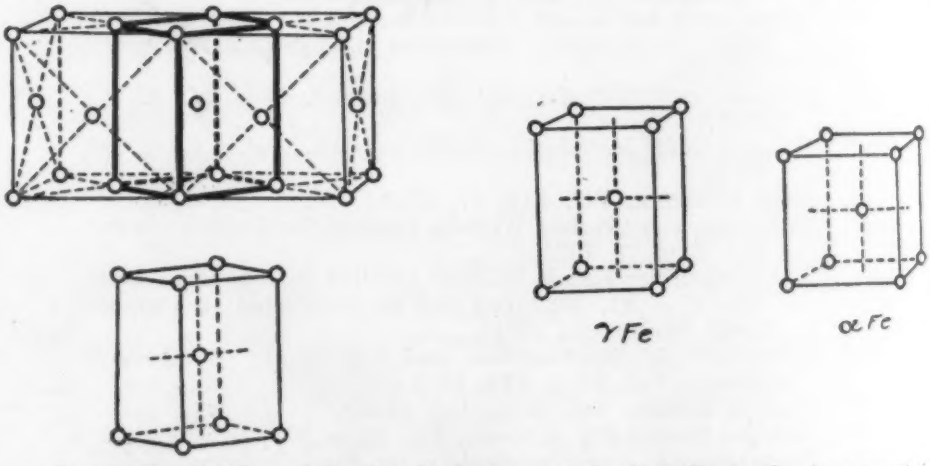


Fig. 1—The Relation of the Atomic Arrangement in Austenite to the Arrangement in Ferrite.[1]

are greatest when the atoms are farthest from equilibrium position and gradually become less as the atoms reach the final position. (As though they were held by springs). Or suppose that the atoms themselves became more sluggish as the temperature drops and are more reluctant to assume the final exact position. Either assumption is not difficult to make and would imme-

[1] "The Nature of Martensite," Edgar C. Bain, New York Meeting, American Institute of Mining and Metallurgical Engineers, February, 1924.

diately explain why the final condition in martensite does not exactly correspond with *perfectly* cubically-crystallized alpha iron. Now the inference is that, if the atoms do change by some such shift as we have pictured, then the final state reached in martensite which does not permit equilibrium, would be slightly tetragonal.

If one could have the whole of a large number of grains pass simultaneously through the allotropic change slowly, and could view the X-ray pattern as the change transpired then he would see a movement of the diffraction lines as shown in this chart (Fig. 2). Some of the single lines in either system divide in the tetragonal intermediate condition and reunite differently in the other form.

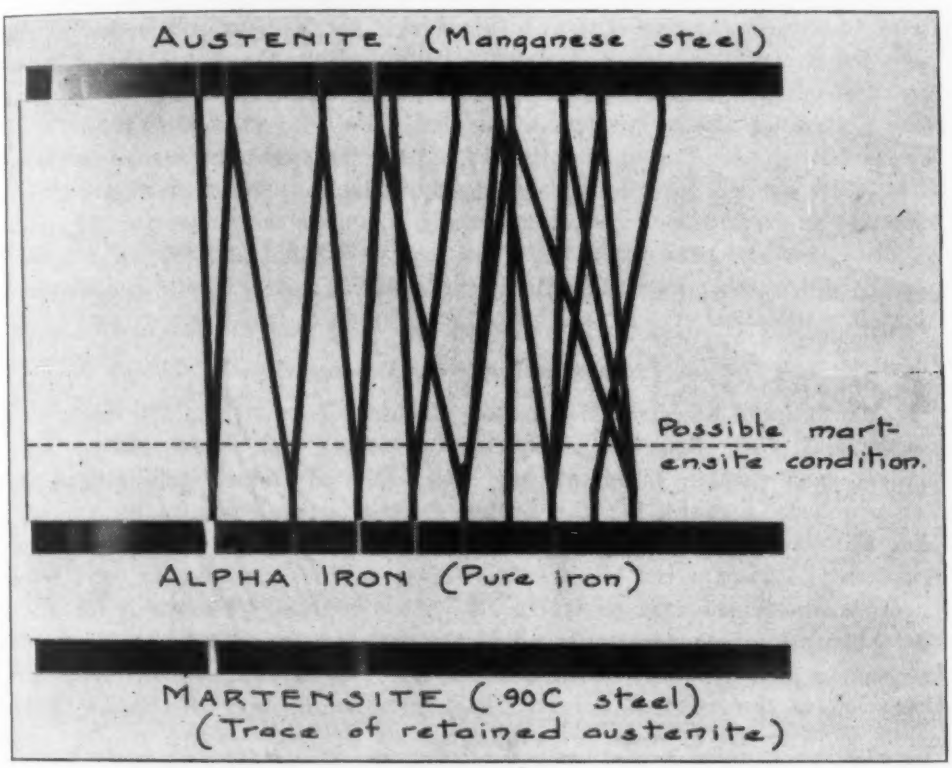


Fig. 2—Ideal Diagram of the X-ray Pattern Change Accompanying the Change from Austenite to Ferrite (+ Carbide).

The disturbance in the pattern at a slight departure from alpha iron is somewhat like our patterns of freshly quenched martensite showing broadened and doubled bands. Hence it may well be that in martensite the allotropic change is arrested just short of perfect crystallinity due to the rigidity of the atom structure at the low temperature of martensite formation.

I doubt greatly that one should attempt to assign an actual ratio to the axes in martensite. There could scarcely be a great preponderance of the tiny grains which would stop their internal atomic reorganization at a specific point,—the figure given by Mr. Fink then represents a statistical maximum in the distribution.

Furthermore, that this tetragonal condition—a stopping point of allotropic change—contains in it the essence of hard martensite must not be assumed, for when specimens are reheated it appears that restoration is established to the cubic condition of alpha iron at about 100 degrees Cent. *without any sacrifice in hardness.*

This knowledge, while not establishing, in any sense, a simple explanation of hardness in quenched steel marks certainly an advance in our lines of attack upon heretofore unknown ground. It is a step forward in our sincere struggle to determine the nature of martensite and to replace, as advancement permits, mere names with definite knowledge.

H. M. BOYLSTON: I wondered as I heard Mr. Fink and Mr. Bain, whether our old friend *beta* iron had risen once more from the grave where some have tried to bury it. It begins to look to me as if the X-ray spectrometer is going to show a crystallographic change—an intermediate change—between gamma and alpha iron. Even the stereopticon[1] took an unfair advantage of the situation and drew a nice bright curve through Mr. Bain's lantern slide, which might be considered a first approximation of a plane through martensite. Although I have not studied these data at all closely, it looks to me as if we are getting closer to an explanation of what martensite is, and to the reason for the critical point commonly known as A_3. Whether we should call it an allotropic change and whether we should dignify it with the name of beta iron may have to wait a little longer. I thank you.

Author's Reply to Discussion

Mr. Bain in his discussion called attention to the generally recognized geometrical fact that the body-centered cubic and face-centered cubic lattices are special cases of the body-centered tetragonal lattice, and attempted to account for the author's experimental results by assuming that the mechanism of the transformation is a continuous variation of the axial ratio. This is the simplest and most obvious explanation, and seems to contain some element of truth. However, it does not account for all of the facts, and after going over all of the data we concluded that the actual mechanism was probably more complex. Mr. Bain in his discussion called attention to the weakest point of such an explanation. He said, "There could scarcely be a great preponderance of the tiny grains which would stop their internal atomic reorganization at a specific point,—" The experimental facts are that for a 1.50% C steel, distinct lines were obtained for an axial ratio of 1.06, or in other words that a great preponderance of the tetragonal lattice was at that specific point.

The facts could be explained much better by assuming that the tetragonal lattice with an axial ratio of 1.06 is formed in a discontinuous manner, and that a continuous change may then take place between the axial ratios of 1.06 and 1, or may be suppressed to a greater or less extent. However, the data are not sufficient to warrant any definite conclusion as to the exact nature of the tetragonal lattice, and, as was stated in the

[1]Prof. Boylston refers to the cracking of the slide which Mr. Bain used in discussing Mr. Fink's paper. This slide is reproduced as Fig. 2 in Mr. Bain's discussion.

(Continued on Page 780)

THE LABORATORY AS A FACTOR IN THE INSPECTION OF ALLOY AND TOOL STEEL

By W. H. Wills, Jr.

Abstract

The author is of the opinion that it is becoming the practice, especially with large users, to purchase tool steel by physical and chemical specifications, rather than by the manufacturer's brand name only.

Users of steel are studying their problems and are conducting research work along the lines of chemical composition, improved machining qualities, new processes of heat treatment and physical examinations to meet the demand for better quality products.

A well-equipped, well-manned laboratory is, in his opinion, a good investment to a producer as well as to a large consumer.

THE laboratory has existed for some time as an important part of every steel mill. More recently it has been finding its place in the plants of most large users of steel. Its importance continues to grow as standards of quality become higher and specifications more exacting.

The purpose of this paper is to take up the matter of specifications and inspection as applied to tool steels, ball bearing steel, and the other high quality alloy steels, rather than the S. A. E. or engineering alloy steels. In other words, the discussion will be limited to the product turned out by the tool steel mills and how the laboratory plays its part in the inspection.

Not many years ago tool steels were purchased almost entirely by brand name. Little mention was made of analysis. The customer placed his order for a given brand for a certain purpose and left the specifications up to the steel maker. Things have changed considerably, however, and it is becoming the practice, especially with large users, to order tool steel to their specifications, rather than by the manufacturer's brand name only. This applies in particular where the steel is the raw material. There are good reasons for this. The users of steel are studying their production problems closer than ever before. Failures of tools

A paper presented before the Buffalo Sectional Meeting of the society, January, 1926. The author, W. H. Wills, Jr., member of the Buffalo Chapter of the society, is metallurgist, Atlas Steel Corporation, Dunkirk, N. Y.

in service are being closely investigated and constant research is carried on to improve the finished product. As a result, the user is gaining a better knowledge than ever before of just what his requirements are.

With this in mind, let us enumerate what items these specifications may include. In the first place, there is chemical composition. The limits or range allowed for the different elements will vary, depending on the type of steel. The following limits are commonly used:

Carbon	.5 to 10 points[1]	Vanadium	.10 to 20 points
Manganese	.10 to 30 points	Tungsten	(low) 25 to 50 points
Phos & Sulphur	.0.030 max.		(High) 100 to 200 points
Silicon	.10 to 20 points	Molybdenum	.10 to 20 points
Chromium	(low) 20 points	Nickel}	
	(High) 100 to 200 points	Cobalt}	.50 points

Then there is size tolerance, which varies with the size and shape of the section. Tolerances on cold drawn material are, of course, much closer than on hot-rolled stock.

Another item in the case of bar stock is length. Usually a three or four-foot leeway is stated. Sometimes multiples of a given length are called for. Most users require that the bars be perfectly straight. In the case of hot-rolled or cold drawn coils the weight and size of the coils are specified.

Surface decarburization, or bark, is another consideration which is stressed by many buyers. Proper allowance for bark means economy of raw material on the one hand and less rejections of finished product on the other. A certain amount of bark on hot-rolled stock is unavoidable under present conditions of manufacture. Holding it to a minimum requires care in all the heating operations from the heating of the ingot for cogging down to the annealing of the finished bars. Some grades of steel decarburize more readily than others. Straight carbon and high carbon chromium ball steel will become decarburized about as readily as any steel. Those of higher alloy content are less susceptible to decarburization and high speed steel is still less. This is a fortunate condition when we consider the relatively high temperatures to which such steels are subjected in forging, annealing and hardening.

Hardness is another item. Annealed stock is usually ordered to a certain Brinell hardness with a twenty to thirty point range.

[1] A point is equivalent to 0.01 per cent.

Sometimes maximum Brinell number only is given. Some customers will specify a Shore hardness. In the case of small cold drawn sections a Rockwell B scale range is often called for.

Closely related to hardness is structure. Where the stock is to be worked on automatic machines, the best machining qualities are obtained when the cementite is largely in the spheroidal condition. For some operations a 100 per cent spheroidal condition is desired and this is the best condition for proper hardening.

Fig. 1—Making Microscopic Examinations.

In other cases the ideal structure is obtained with the lamellar pearlite about three-quarters broken up. As a rule, grain boundary cementite and excessive lamellar pearlite are objectionable in annealed structures. These structures are characteristic of such grades as straight carbon, carbon-vanadium, chromium bearing, and the high manganese oil hardening steels when not properly annealed. A number of large users specify a certain structure desired on annealed stock.

In the high alloy steels, particularly high speed steel, there is greater chance for carbide segregation and traces of original ingot structure. In these types the structure is affected to a

large extent by the method of mechanical working, and not so much by the annealing as the low alloy steels.

No matter what the type may be, uniformity of structure is important not only in relation to machining qualities, but also in connection with proper hardening and, finally, proper performance.

In addition to the above items several other general specifications may be mentioned, such as:

Good surface condition, free from laps, seams, ridges, pits or excessive scale.

Freedom within good commercial practice from segregation or inclusions, metallic and nonmetallic.

Ability to harden properly.

Method of manufacture—referring to manner of melting—crucible, electric or open-hearth.

Method of marking.

To show practical application of the above specifications, a few typical illustrations have been selected.

Specification (I) covers hot-rolled carbon tool steel for the manufacture of twist drills.

Specification (II) covers hot-rolled high speed steel for general purposes in manufacturing operations.

Specification (III) covers cold drawn carbon tool steel.

Specification (IV) covers cold drawn ball wire used in the manufacture of balls for ball bearings.

SPECIFICATION I

COVERING HOT ROLLED CARBON TOOL STEEL FOR A MANUFACTURER OF TWIST DRILLS

Analysis

15/16 inch round and smaller

	per cent		per cent
Carbon	1.25–1.33	Sulphur	0.020 max.
Manganese	0.20–0.30	Silicon	0.10–0.25
Phosphorus	0.020 max.		

Over 15/16 inch round the following analysis applies with carbon content as noted below:

For sizes 31/32 to 2 inches ..... Carbon 1.15–1.24 per cent
2–1/16 inches and larger ..... Carbon 1.21–1.29 per cent

	per cent		per cent
Manganese	0.20–0.30	Silicon	0.10–0.25
Phosphorus	0.020 max.	Chromium	0.40–0.60
Sulphur	0.020 max.		

Upon receipt of a shipment of steel, samples from several bars of each size will be selected at random for chemical analysis. The number of pieces analyzed from a particular size will be governed by the weight received and the size of the bars.

The chemical composition of each sample of a given size must be within the limits given above, any variation rendering all bars of that particular size subject to rejection.

Tolerances:

Size Round	*Tolerances in inches*
½ inch round	.....0.003 under to 0.005 over
Over ½ in. round and including ¾ in.	.....0.003 under to 0.007 over
Over ¾ in. round and including 1 in.	.....0.005 under to 0.010 over
Over 1 in. round and including 1½ in.	.....0.005 under to 0.012 over
Over 1½ in. round and including 2 in.	.....0.007 under to 0.015 over
Over 2 in. round and including 3 in.	.....0.010 under to 0.018 over
Over 3 in. round and including 4 in.	.....0.015 under to 0.025 over

Physical Properties:

A. Bars exhibiting physical defects, such as cracks, flaws, seams, pipe, twist, will be rejected, notwithstanding the fact that said defects are not revealed until manufacturing operations have been performed on the bars.

B. Bars must be straight and true to gage, the minimum length of bars shall be 8 feet, but lengths preferred are from 10 to 12 feet.

C. All bars must be within the Brinell hardness limits of 170 to 196 inclusive, or Rockwell hardness of 85-95 B inclusive.

D. The microstructure desired is a semi-spheroidal condition, that is, the pearlite is approximately three-quarters broken up and no grain structure whatever should be visible.

E. Decarburization must not exceed the following limits on a side:

½ inch round .....0.008 inch
17/32 inch to 1 inch round inclusive .....0.012 inch
Over 1 inch round .....0.015 inch

F. All bars, especially the larger ones, must show a thoroughly "worked" and strong center.

SPECIFICATION II

Covering Hot Rolled High Speed Steel for General Purposes for a Concern Using it in Their Manufacturing Operations

General Description

The material desired is an annealed 18-4-1 type high speed steel which will respond to hardening and tempering suitable for high speed cutting tools.

Requirements

General: The high speed steel covered by this specification shall be made by the crucible or the cold melt electric furnace process.

The steel, within the meaning of good commercial practice, shall be free from segregation occluded oxides, slag and other impurities as determined by micro and macro analyses.

The production of the shape from the ingot shall be accomplished by sufficient reduction in cross section to insure proper refinement of the structure and the uniform distribution of the carbides.

The surface decarburization shall be kept at a minimum.

The bars or shapes shall be as straight from end to end, and as smooth and free from flaws such as pits, slivers, seams, cracks, dents, and soft or hard spots as good commercial practice will allow.

The steel shall be delivered in the annealed condition suitable for machin-

ing. It shall be in such condition that it will respond to hardening and tempering suitable for 18-4-1 high speed tools.

Chemical: The steel when tested according to the latest published methods of the United States Steel Corporation shall conform to the following composition:

	Minimum Per Cent	Maximum Per Cent
Carbon	0.65	0.75
Manganese	0.10	0.40
Sulphur	...	0.035
Phosphorus	...	0.035
Silicon	0.15	0.35
Chromium	3.50	4.50
Tungsten	17.00	19.00
Vanadium	0.80	1.10

Brinell Hardness Unless otherwise stated on the purchase order, annealed steel with a Brinell hardness of 230 is desired, and no steel with a Brinell hardness of over 245 will be accepted.

Dimensional The dimensions shall be as specified on the purchase order. When the tolerances are not specified on the order variation in gage, diameter width, thickness and length, shall be in accordance with good commercial practice.

Finish The finish shall be as specified on the purchase order.

Marking and Painting The number (1) with the code letter shall be clearly punched on or near both ends of each piece. This number is an arbitrary code of the customer for his use in inspection and maintaining the identity of the stock. Each piece shall be painted BLUE for its entire length, and about one-half of its surface.

Selective Tests Selective tests will be run whenever it is deemed advisable by the customer for the purpose of approving sources of supply.

Suppliers may submit proposals on tool steel, which differs from the composition and the method of manufacture specified, provided they are accompanied by a statement of chemical composition and method of manufacture. This information will be considered confidential if the supplier so requests.

SPECIFICATION III

Covering Cold Drawn Carbon Tool Steel

Analysis

	per cent		per cent
Carbon	1.25–1.33	Sulphur	0.020 max.
Manganese	0.20–0.30	Silicon	0.10–0.25
Phosphorus	0.020 max.		

Upon receipt of a shipment of steel, samples from several bars of each size will be selected at random for chemical analysis. The chemical composition of each sample of a given size must be within the limits shown above; any variation rendering all bars of that particular size subject to rejection.

Tolerances: will be specified on each order.

Physical Properties:

A. Bars exhibiting physical defects such as cracks, flaws, seams, pipe, twists,

will be rejected notwithstanding the fact that said defects are not revealed until manufacturing operations have been performed on the bars.

B. Length of bars will be specified on each order.

C. Decarburization must not exceed the following limits:
Rough drawn—total decarburization must not exceed 0.006 inch.
Polished drill rod must be free from decarburization.

D. Polished drill rod 5/16 inch and smaller must Rockwell 90 to 100-B inclusive.
Readings to be taken on a flat surface.
Rough drawn rod 15/64 to ⅝ inch must Brinell 187 to 217 inclusive, A 10 millimeter ball and 1500 kilogram load will be used.

E. The microstructure desired is a semi-spheroidal condition, that is, the pearlite should be approximately three-quarters broken up and no grain structure whatever should be visible.

SPECIFICATION IV

Covering Cold Drawn Ball Wire Used in the Manufacture of Balls for Ball Bearings

Chromium-Carbon Ball Wire Cold Drawn

Annulments:

1. This specification supersedes all previous specifications covering this material.

Manufacture:

2. Material must be made by the electric furnace process.

Quality:

3. The material must be of the highest quality in every respect of uniform composition and free from segregation.
4. The surface of the wire must possess a good finish and be free from rust, scale, or any foreign matter that is hard or gritty, or which will be deterimental to its shearing or cold heading quality.
5. The wire must be free from surface imperfections such as seams, rolling laps, pitting checks or laminations to the extent that upon removal of 0.005 inch of stock from the surface of the wire the defects will be entirely removed.
6. If more than 10 per cent of the shipment contains defects greater than our permissible limit, the whole of the lot in question is liable to rejection without further examination.
7. Providing the surface defects are within the limits as required by clause 6, the whole of the shipment will receive an inspection covering both ends of each coil. All coils containing defects greater than our permissible limit will be set aside to be returned for full credit.
8. The interior of the stock must be free from porosity, slag or other inclusions, especially those which break the continuity of structure close to the surface, also pipes and abnormal porosity at or towards the center of the stock, to the extent that the stock will be equivalent in quality to that representing the best modern practice.
9. The material as received at our plant must possess a fine, uniform grain structure of a quality consistent with good mill practice.

Decarburization:

10. The surface of the wire must be free from decarburization to the extent that upon removing 0.004 inch from the radius of the wire the remaining section will retain its full quota of carbon, as called for under "composition."
11. The wire should harden in oil or water according to its size, without the removal of surface metal. The hardened samples must be file hard

below the 0.004 inch limit and must have a uniformly fine grained fracture indicative of a tough strong steel.

12. Sizes below 0.100 inch diameter are water quenched; from 0.100 inch diameter up to and including 0.235 inch diameter are quenched in oil; and sizes above this are water quenched.

Regarding Presence of Carburization at and Near Surface of Wire:

13. All of the shipment of a given size of wire will be rejected if carburization appears in any of the coils below 0.005 inch from surface. The percentage of carbon found below the limit given must conform to the restrictions for composition, Section 14.

Composition:

14. Upon receipt of stock at destination, samples selected for analysis must show the material to be within the following requirements:

	per cent		per cent
Carbon	0.95 to 1.05	Silicon	0.20 to 0.35
Chromium	0.45 to 0.65	Sulphur under	0.025
Manganese	0.30 to 0.45	Phosphorus under	0.025

Brinell Hardness and Microstructure:

15. The Brinell hardness of the stock as received (5 millimeter ball under 1000 kilogram pressure) must not be below 180 or above 210 at any point in the length or any point in the cross section.

16. The material must be thoroughly and uniformly annealed so as to meet the Brinell requirements given above, while the carbides must have a fine globular structure, uniformly distributed.

Coil Size and Size Tolerance:

17. A coil is considered as consisting of one unbroken length of wire.

18. If the ends of the coils are tapered down or are imperfect in any way they must be "cropped off."

19. The coils must not be less than 18 inches inside diameter or greater than 34 inches outside diameter. Wire of heavy cross section should be wound in as large coils as possible, but within the limits given.

20. The coils should not weigh less than 80 pounds or more than 110 pounds for wire above 0.235 inch diameter. Coils of wire below 0.235 inch diameter may weigh as low as 60 pounds.

21. The wire must be true to the diameter ordered within the limits of plus 0.002 inch and minus 0.002 inch.

Shipping:

22. Coils must be reeled uniformly and must not be in a distorted condition when received and the layers must be bound securely with separate tie wires to keep them in good shape during transportation so that they may be unwound properly without tangling.

23. When two or more different sizes are shipped together in the same car, they must be so secured and located in the car that they will not become mixed during transportation.

The inspection covering a number of the above items is taken care of in the warehouse or shipping department of the steel manufacturer. Among these may be included size of section, length, surface, fracture, Brinell hardness and the marking.

It is the laboratory's part to carry out such inspection, as check chemical analysis, examination for surface decarburization, checking of hardness in certain cases, and examination of internal structure. Not many years ago such laboratory inspection

was rare or uncalled for, simply because specifications could be met without it. Nowadays a large and increasing number of orders require it, if the buyer is to be satisfied and rejections held to a minimum. This need of a closer check on the quality of the product has been one of the things that has contributed to the recent growth and development of the laboratory. The idea of technical control has been carried all the way through from raw

Fig. 2—Checking the Hardness of Tool Bits.

materials to finished product in modern plants. The laboratory, in plants of any size, comprises two divisions—the one taking care of chemical testing and the other physical testing—often called the metallurgical laboratory. They are run by separate personnel as a general rule.

One of the principal duties of the chemical laboratory in a steel plant is the analysis of preliminaries from the melting department and the analysis of ladle tests or ingots. The matter of close checks on carbon is very important, especially when working to 5-point ranges. It is the regular practice at one laboratory to run several checks on two ladle tests and in case of more than one point variation the ingots are checked from that heat. It is the practice, from time to time, to check the carbon as well as the alloy content of ingots from a given heat for comparison with

corresponding ladle test results. The analysis of the incoming raw materials, such as purchased scrap, ferro alloys, melting bar, fuel, etc., is a regular duty. These are usually purchased according to specifications and must be analyzed and approved before using. The analyses run for the metallurgical laboratory in connection with its investigations amount to considerable. The nature of these investigations will be gone into a little further

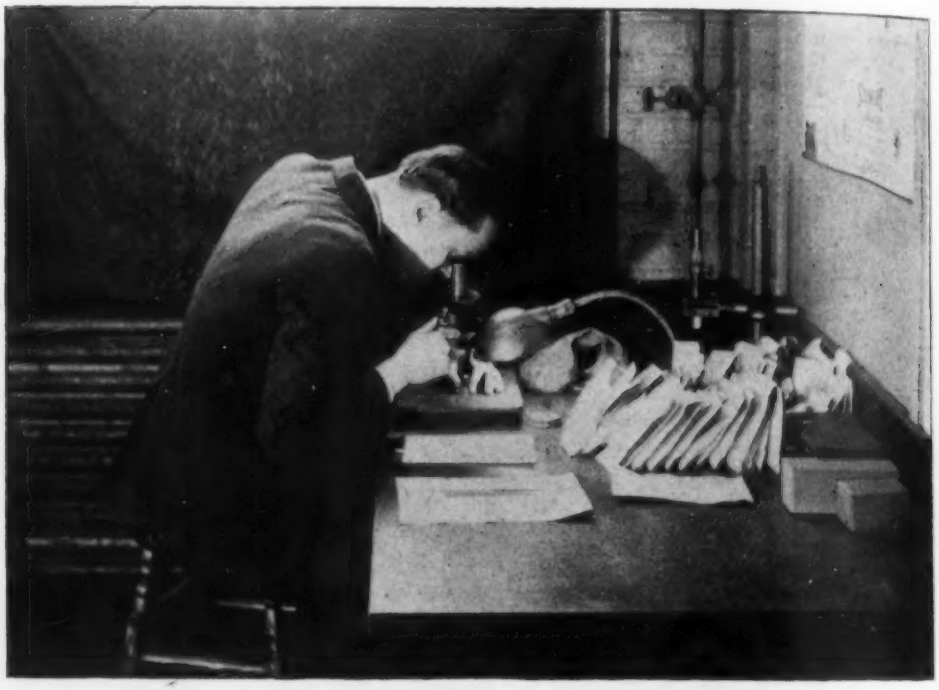


Fig. 3—Examination of Hardened Fractures for Decarburization under Low Power Binocular Microscope.

on. A further duty of the chemical laboratory is the check on semi-finished or finished stock, both hot-rolled and cold drawn, to be sure of meeting specifications. This means an additional duty, but must be looked upon as a necessary precaution to maintain quality. Comparison is made with the original heat analysis and it is interesting to note that in a number of heats followed through, 97 per cent of the bars check the ladle ($\pm$ 0.02 on carbon content). Figures over a period of several months show that the laboratory will average about 7000 determinations monthly and of these 75 per cent are in connection with the melting department, 10 per cent metallurgical department, and 15 per cent work on semi or finished products.

The development of the physical or metallurgical laboratory

in the last few years has been especially marked. The scope of its work has broadened greatly. This has been due not only to the demand for better quality of product, but also to the progress of the science of metallography and heat treatment of steel, the closer co-operation with users in solving their problems, and the greater attention paid to research work. Along with this has come the need of more varied and improved equipment. The

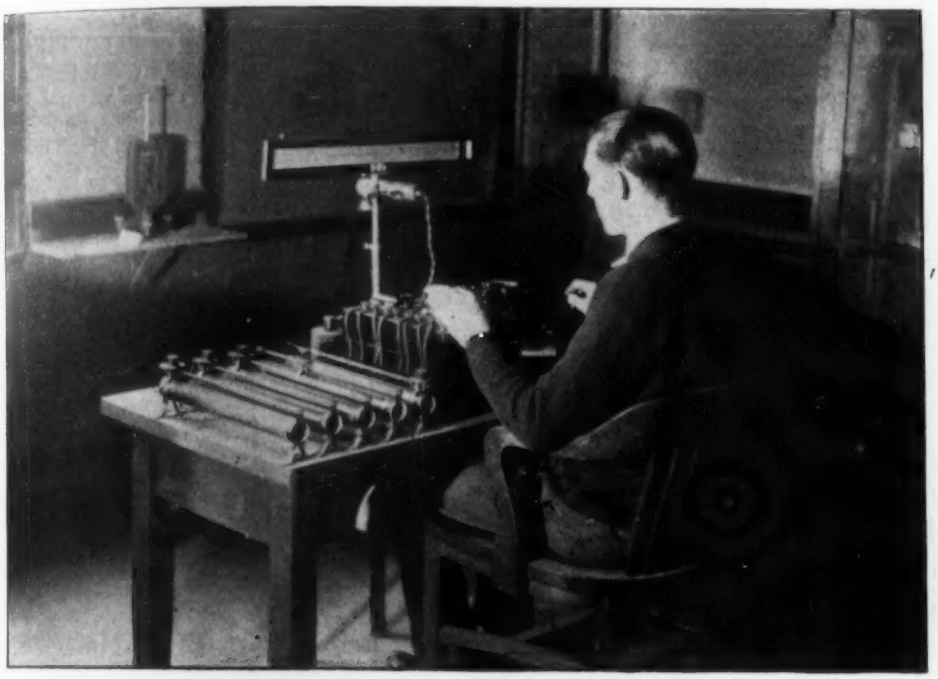


Fig. 4.—Determining the Residual Strength and Coercive Force of Permanent Magnet Steel.

metallographic phase of the work has made the microscope an essential piece of equipment of the laboratory, whether it be one of the simple types suitable for examination at comparatively low magnifications, or the more complex outfit permitting observation and the taking of photomicrographs at several thousand diameters. Along with the microscope go such accessories as the equipment for cutting and polishing specimens and also the requirements for photography work.

The Brinell hardness tester and tensile testing machine have long retained their places and today play an important part in both routine and research work. The former is probably more generally used than any other device for testing annealed stock and heat treated steels. To some extent the Brinell machine is

used on hardened tool steels but more generally the scleroscope and the Rockwell tester are taking care of this work. Impact testing machines figure to quite an extent in experimental work.

More or less pyrometer equipment is to be found in the average laboratory. This is a line that has been greatly improved and is being more widely used as control of temperatures in various manufacturing processes is extended. Accurate temperature measurement is required in most experimental work. Consequently, the laboratory usually has in its possession one or more standard instruments that are used as a basis for checking those in service on production work throughout the plant.

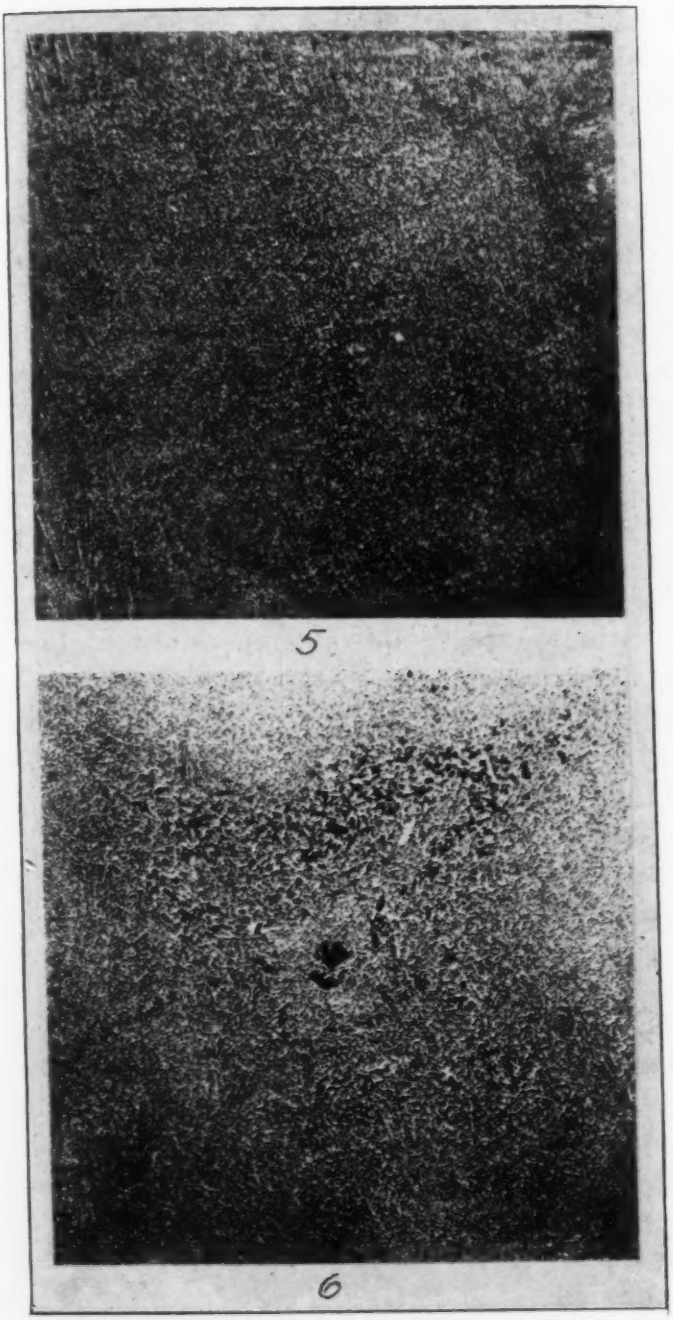
Magnetic testing apparatus is used to some extent in research investigations and is likely to come into more general use in the future. Tool steel mills specializing in magnet steel, as well as manufacturers who use it in large quantities, find the permeameter a useful device for the routine testing of this type. With this instrument it is possible to determine the whole hysteresis curve of a specimen.

The laboratory equipment is hardly complete without one or more furnaces for general heat treating work, experimental or otherwise. The various types of electric resistance furnaces are found especially suitable, since the temperature can be closely controlled and there is absence of fumes. Electric melting furnaces find considerable use for experimental purposes.

Incoming Materials Inspection

Let us now consider briefly some of the physical laboratory tests that have become a routine matter on many orders, and also applied by many users on the incoming material. First, there is microscopic examination of a representative number of samples, depending on the size of the lot. Examination for inclusions in general is best done with the specimens unetched at a rather low magnification, such as 100 diameters. Annealed structures of tool steel are usually observed at 250 to 500 diameters. With high speed types the carbide distribution in the annealed condition is seen to advantage at 125 to 250 diameters.

Decarburization, or bark, may be conveniently measured at low power except when very slight. It is easier to observe on annealed stock than on unannealed, particularly when the annealed structure is completely spheroidal, or nearly so. In this



Figs. 5 and 6—Good and Bad Deeply Etched Sections (¾ inch square) Chromium-Molybdenum Steel. Approximate Etching Time 45 Minutes in Hot 1:1 Hydrochloric Acid. Magnification 3½ diameters.

case, with a fairly heavy bark, there will be some ferrite along the outer edge. This will give way to a structure consisting largely of lamellar pearlite, which will continue until the

spheroidized part is reached and the carbon is constant. When the bark is slight, little or no ferrite will be found. Decarburization on high speed steel does not stand out as pronounced as on carbon steel. The structure of the decarburized portion is distinguished by the presence of fewer and smaller carbides than obtain in the body of the specimen. Where a large number of bars of small section are to be tested for bark, a convenient and accurate method is to examine the hardened fractures under a low power microscope. The samples must, of course, be hardened in a molten bath, preferably lead, so as not to decarburize further. The method may be applied to any grades that can be hardened in lead.

The deep etch test is employed to quite an extent for certain kinds of inspection work. Hydrochloric acid is most commonly used for this purpose. In conducting this test there are four variables to be considered: first, the concentration of the acid; second, time in the acid; third, temperature of the acid; and, fourth, the finish or condition of the sample under test. The first three affect the depth of the etching, in that it is roughly proportional to the strength of the bath, time of immersion, and temperature of the bath. The fourth variable refers to whether the sample is in the annealed, as-rolled, hardened, or cold drawn condition. If, therefore, intelligent results are to be obtained or comparisons made, these factors must be taken into account. Irregularity shown by a deep etch test may be due to several causes. Inclusions, segregation, or traces of pipe, will, of course, be magnified. The same is true of surface seams. Variation in structure will have its effect. Also a strained condition in the sample will be brought out, as is often the case with samples from unannealed or drawn stock. These last named cases are apt to be wrongly interpreted as defects, particularly when unannealed stock is being inspected. This method of testing is especially valuable for testing bars whose centers are to be subject to great stress or wear, such as hot or cold heading dies and certain kinds of forming tools.

The routine hardness testing of finished products usually comes under the supervision of the laboratory. Brinell tests are run on a representative number of samples from each annealing heat. Semi or mill floor annealed material—generally magnet steel, is checked for hardness in the same way. On orders for cold drawn steel bars, samples representative of each are tested

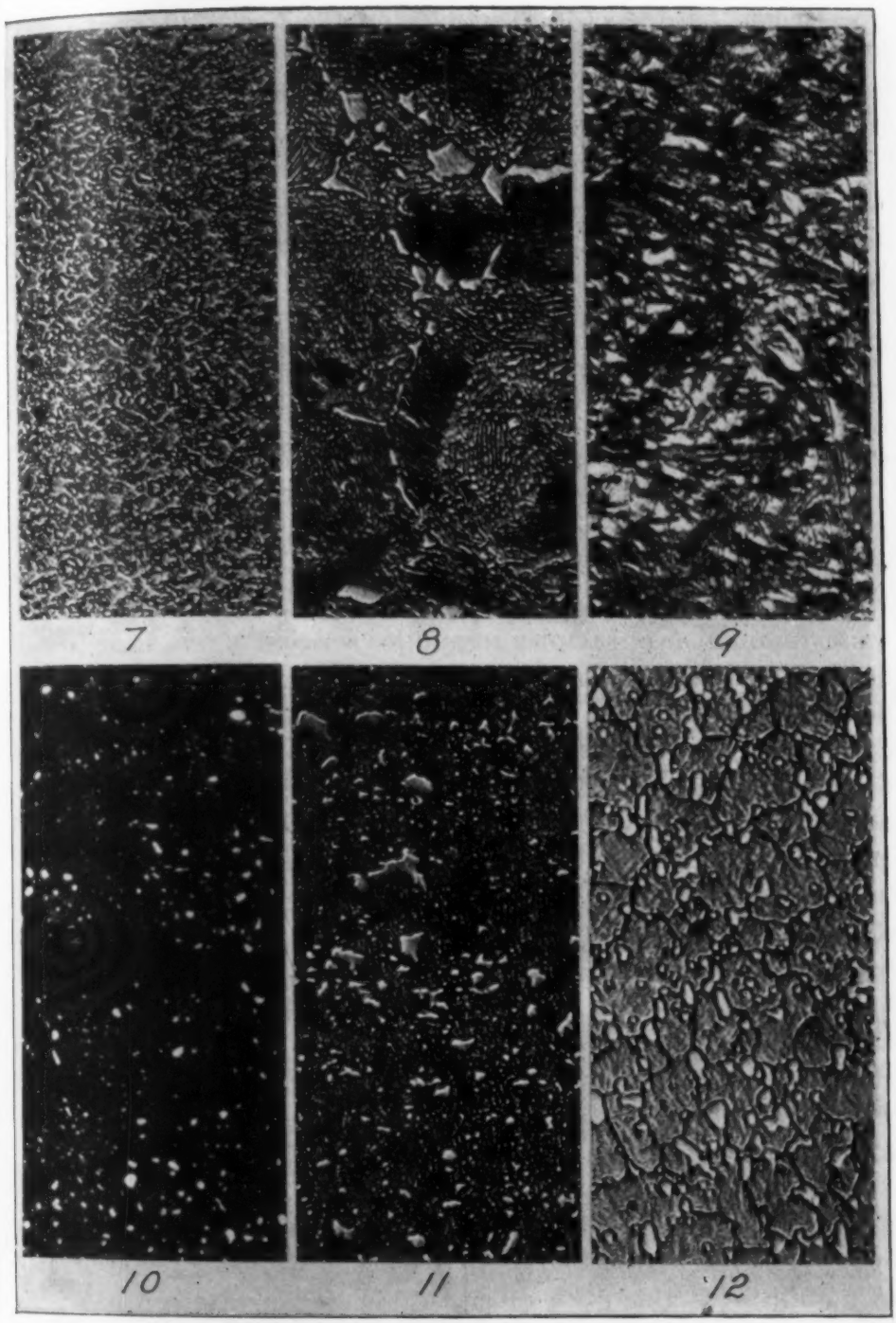


Fig. 7—Well-Annealed Carbon-Vanadium Steel. This Spheroidal Structure is also Typical of Straight Carbon, Manganese Oil Hardening, and Chromium Bearing Steels when Properly Annealed. Magnification 500 x. Fig. 8—Poorly Annealed Structure of 1.20 per cent Carbon Steel Showing lamellar Pearlite and Traces of Grain Boundary Cementite. Magnification 500 x. Fig. 9—Overheated Structure of Managese Oil Hardening Steel. Magnification 500 x. Fig. 10—Non-Metallic Inclusions in Hardened Chromium Bearing Steel. Magnification 500 x. Fig. 11—Typical Annealed Structure of High Speed Steel. Taken from 2 inch by 1 inch Section. Magnification 500 x. Fig. 12—High Speed Steel as Quenched from 2350 degrees Fahr. no Draw. Showing Austenitic Structure. Magnification 500 x.

for Brinell hardness, or sometimes on the Rockwell tester. Heat treated tool bits and cut-off blades are checked for hardness on the scleroscope or Rockwell hardness tester, using the diamond point. Most of the orders are filled from stock and standard size bits made for stock are treated for maximum hardness with a high draw, aiming to have the austenite completely broken up. It is not necessarily true that the bit showing the highest degree of hardness makes the best cutting tool for all purposes, but experience has shown that by giving them this treatment the best all around performance is obtained.

The examination of hardened fractures is a useful test on many grades, particularly ball bearing steel and the high speed grades in large sections. On certain types, particularly carbon tool steel, examination of carburized samples furnishes a reliable indication of the way the steel will harden.

Another finished product whose inspection requires the attention of the laboratory is permanent magnet steel. A representative number of samples from a lot are first checked for Brinell hardness. They are next carefully hardened and tested on the permeameter for residual strength and coercive force. To obtain the highest coercive force, magnet steel should be subjected to the fewest possible heating operations. For this reason many users adjust their operations so they can handle it mill floor annealed. In this condition the Brinell hardness runs 302 to 375 and the bars can be cold-sheared to length. When the magnets are to be stamped out cold from flat bar stock or where considerable machine work must be done, the bars are annealed to certain Brinell hardness limits. This reduces the coercive force depending upon the extent of the annealing. Fully annealed chromium magnet steel will run 179 to 187 Brinell, while tungsten magnet steel will run 196 to 207, and the falling off in coercive force will amount to twenty to twenty-five per cent.

While the various tests outlined above in connection with the production end demand much of the laboratory's time, the modern practice of giving service to customers has added considerably to the duties of this department. This service may consist of the investigations of a complaint. It may be experimental work to determine whether a certain grade of steel is suitable for some special requirement, or the solution of a heat treating problem. Records of one manufacturer show that over a nine months'

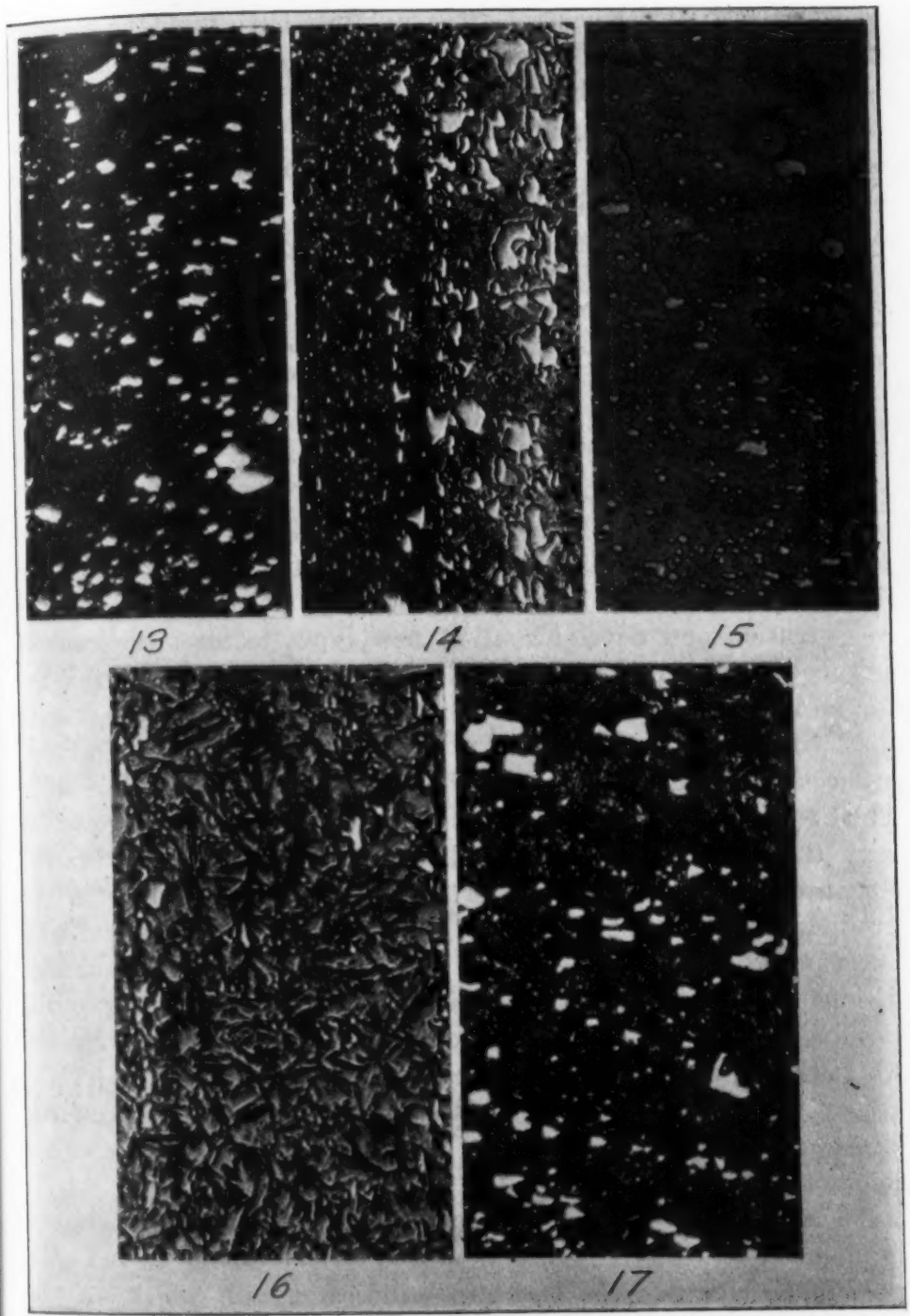


Fig. 13—High Speed Steel Properly Hardened and Drawn at 1100 degrees Fahr. Magnification 500 x. Fig. 14—High Speed Steel Hardened and Drawn, Showing Carbide Segregation and Surrounding Retained Austenite. Magnification 500 x. Fig. 15—High Speed Steel Showing Improperly Hardened Structure. The Tool from which this was Taken was Overheated and not Drawn and Showed a Coarse Spangly Fracture. Note Grain Size as Compared with Fig. 12. Magnification 500 x. Fig. 16—High Speed Steel Showing Structure Typical of Mild Overheating and Incomplete Drawing. Magnification 500 x. Fig. 17—Showing how Structure Shown by Fig. 15 can be Improved by Further Drawing at 1100 degrees Fahr. Magnification 500 x.

period about 30 per cent of all complaints have been the fault of the customer and in the majority of these cases it was improper heat treatment. Of the complaints laid to the manufacturer the largest part was on account of internal structure, or defects which of course are the most difficult to observe on the inspection before shipment. The investigation of a complaint usually involves check analysis to determine whether the grade of steel used was correct. Among other things that may be looked into are fractures, structure, hardness, or examination for bark, or inclusions.

Besides complaints, the laboratory is continually making examination of various samples, competitors' grades or otherwise, and acts as a clearing house for information along metallurgical lines for the benefit of the sales department.

A description of the laboratory's duties would hardly be complete without including research work. This is a good sized subject in itself, but in bringing this paper to a close only a few lines will be mentioned. One of the ever present problems is the investigation and development of new types to meet the customer's constant requirement for something better. This may be, for instance, a new type automotive valve steel, a high speed steel that will harden satisfactorily at comparatively low temperatures, a shock resisting chisel or punch steel, or a better hot die steel. Then there are constantly things to be looked after in connection with the types of steel included, as the present regular brands. For instance, there may be certain defects or difficulties in the production end to be eliminated or overcome. Information may be required concerning changes of dimension under certain conditions of heat treatment. The improvement of machining qualities may be a problem. A special application may require the working out of a new method of heat treatment to suit. These are only few of the many practical points that call for research effort and form a line of work that can really never be called completed.

From this outline of the various activities of the laboratory in connection with the tool and special steel industry there is one principal thought to be borne in mind, and with which we will conclude our discussion. That is, whether the concern be a producer or large consumer of these products, under present conditions a well-equipped, well-manned laboratory is an investment that pays good returns.

FORGEABILITY OF STEEL DETERMINED BY THE BRINELL MACHINE

By R. E. Kerslake

Abstract

This paper presents a rapid, inexpensive and efficient method of testing steel bar stock as to its suitability for either hot or cold forging or up-setting. A hardened steel cone is substituted for the 10-millimeter ball of the usual-type Brinell testing machine.

THE method of test described in this paper was developed as a result of a need for a quick, simple, effective and inexpensive means of determining the suitability of steel bar stock for cold or hot heading operations. This special test is used in conjunction with routine chemical, physical, microscopic, macroscopic and deep-etch tests usually applied in the inspection of incoming steel bar stock. The requirements of a satisfactory method of test were that it reveal such possible defects as surface seams, pipes, cracks, laps and improper annealing. The test which had previously been used was in conjunction with chemical analysis and was a visual inspection for seams, laps, cracks and together with a filing test to determine the depth and character of any seams, if present. In addition to these tests and in order to determine the forging qualities of the stock it was then subjected to actual forging operations in the shop. Obviously, this was an unsatisfactory method of procedure, because it complicated conditions in the shop routine.

New Method of Test

This method of test was developed under the direction of R. E. Bissell in the laboratories of the Steel Products Company of Cleveland and has been used with much success for several years in the inspection of incoming steel bar stock to determine its adaptability for satisfactory conversion by cold or hot heading into bolts, poppet valves and pins. Fundamentally the test is a modified indentation test such as is employed in the well-known Brinell ball indentation test which is widely used in determining the relative hardness of metallic materials. In place of the 10-

The author, R. E. Kerslake, member, Cleveland Chapter of the society, is assistant metallurgist, Steel Products Company, Cleveland.

millimeter ball which is used in making hardness tests a 60-degree hardened steel cone such as is shown in Fig. 1 is substituted. This cone is attached to the moving hydraulic plunger of a

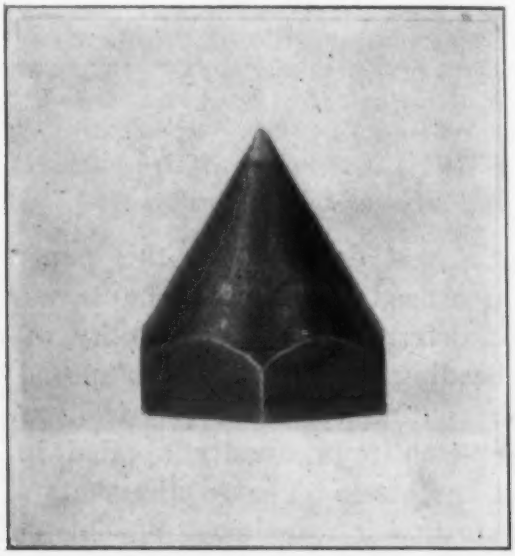


Fig. 1—Hardened Cone Penetrator.

Fig. 2—Specimens Showing a Satisfactory Indentation Test, and the Blank which was Made from this Material.

Brinell hardness testing machine replacing the adaptor which holds the 10-millimeter ball. The anvil upon which the specimen is placed should be of the ball and socket type which provides for

ready aligning of pieces which may have surfaces that are not exactly parallel.

Conducting the Test

To determine the capacity of a given piece of steel bar stock to undergo a heading operation without splitting or cracking a short length or disc (2 to 3 inches) is cut from the bar and ground flat on the cross section. The specimen is then placed on the anvil of the testing machine and impressions are made with the cone

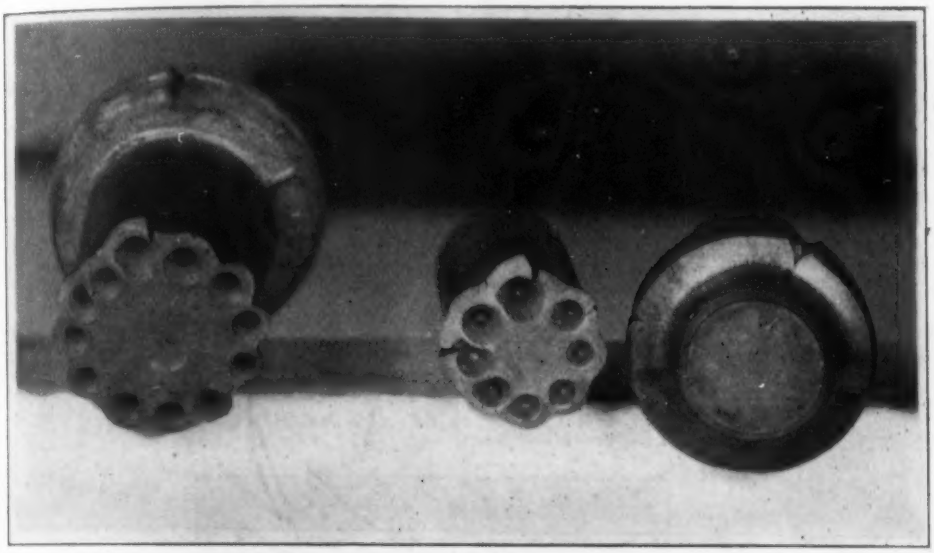


Fig. 3—Examples of Unsatisfactory Stock and Rejected Blanks made from it. These Specimens Show the Presence of Seams and Their Effect on the Blank Made from such Steel.

at points around the periphery of the specimen as shown in Figs. 2 and 3.

In applying the load to the cone, the operator observes the manner in which the specimen responds to the wedging action of the cone penetrator. In the event that the material under test is sound and properly annealed, the specimen will show a condition similar to that of Fig. 2. The amount of penetration that is applied to the specimen varies. If the specimen contains surface seams, the amount of load required to penetrate it will be less than for a similar specimen without the seams, and if the annealing has been improperly done the amount of penetration will vary from one specimen to another. Therefore no specific load can be designated as the proper load for all types of inspection. In making the test the operator observes the characteristics of the material and the amount of up-setting or distor-

tion is evaluated in relation to the observed requirements in actual manufacturing operations. It becomes quite a simple matter to establish definite limits within which bar stock may be accepted for cold or hot heading operations. The angle of the

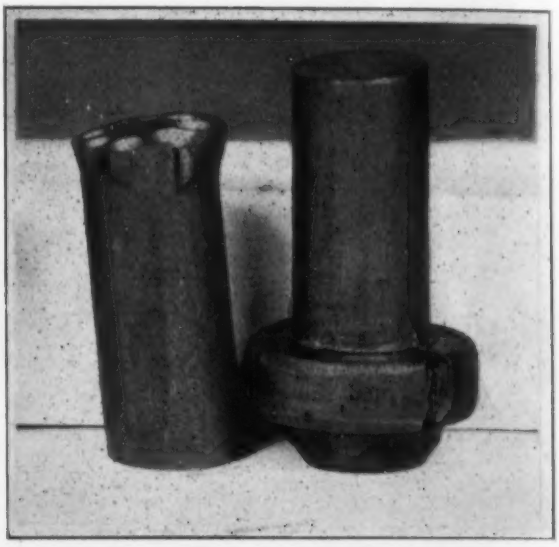


Fig. 4—Specimens of Defective Material Showing the Depth of the Seam.

Fig. 5—Specimen Showing a Black Seam (Unwelded Seam) which almost Invariably Results in Defective Forgings. The Depth of the Seam is Readily Observed.

cone may vary according to the special requirements of the manufacturer and this angle may be determined by test. The test may be applied equally well in the inspection of large sized stock for forging.

IS STEEL "TEMPER"-AMENTAL?

By L. S. Love

Abstract

Several recent experiences might be considered to indicate that steel has its freakish moments and is subject to temperament as well as temper. T. N. Holden, Jr., in charge of the laboratory of the E. W. Bliss Co., Brooklyn, N. Y., is at work checking his solutions to the problems presented. Other steel treaters may already have the answers in their own experience.

WE have always considered that different pieces of steel, when they have like analysis and have been subjected to like treatment, will behave in like manner. This assumption has received an apparent contradiction in a case that has just come to the testing laboratory of the E. W. Bliss Co., Brooklyn, maker of power presses and special machinery. In addition to the regular manufacturing departments, the Bliss company also operates a jobbing shop for the purpose of making stamped and drawn work for users who are not sufficiently well equipped to make certain parts themselves, or do not require sufficient quantities to warrant installation of such equipment.

One such job recently was the making of seamless steel rings. These were drawn from plate blanks 22 and 23 inches in diameter. The press operation is a simple one, consisting, as it does, of merely pressing the blank through dies and drawing the edges into a sort of cup or cylinder with one end open. After this operation, the top edge is trimmed and the bottom of the cup is cut off, leaving a seamless ring of the sides of the cup.

Test pieces were cut from the bottom of the cup. The original blanks were supposed to be identical except for diameter, one being 1 inch larger than the other. A chemical analysis was made of the two before inserting test pieces in the machine for tensile test. The chemical analyses are given in Table I.

Specimens from both blanks were put through identical heat treats. The tensile strength and elastic limits of the specimens from the two blanks were the same. There the similarity vanished. Test pieces from the 22-inch blank showed elongation and reduction of area, anticipated from past experience with pieces

of similar analysis and heat treatment. The fracture was a clean cup and practically at right angles to the axis of the piece. Results were the same with several specimens pulled.

In the case of specimens cut from the other blank, results were quite different. As stated, the tensile strength and elastic limit were the same, but the elongation and reduction in area were much lower. Further, the fracture, instead of being square with the axis, was at a decided angle and, though silky, the structure appeared as of a slightly coarser grain. The first two pieces pulled showed a pipe fracture parallel with the axis; probably due to a flaw in rolling the plate. Because of this the blank was again heat treated with practically the same result, except without the pipe. Several times the piece was heat treated and new specimens cut and pulled, but with the same results.

Table I

	22-inch blank from which perfect fractures were obtained	23-inch blank from which poor fractures were obtained
	per cent	per cent
Carbon	0.49	0.49
Manganese	0.51	0.54
Phosphorus	0.01	0.01
Sulphur	0.019	0.019
Silicon	0.21	0.21

Is this because the second plate was rolled from the top of the ingot and slag inclusions were rolled into it, or is there some other reason?

Peeling of Shell of Shaft Not Case Hardened

Another piece delivered recently to the Bliss laboratory for examination is a wrist pin from a press. This wrist pin is of steel, having a 1.10 per cent carbon content. It shows on the wearing surfaces a Brinell hardness of over 700, but on the inside portions of the shaft, under where the shell peeled off, it is soft enough to file.

It will be noticed from the illustrations, that pieces of varying thicknesses have peeled off. The hardness extends through this layer, but not below it.

The wrist pin was not case hardened, but merely heated to about 1700 degrees Fahr., quenched and drawn. Probably it was reheated, but not given sufficient draw.

The fracture shows a probable incomplete transition from

martensite to troostite, resulting in checks being set up in the hardening operation. These cracks, due to vibration of the press

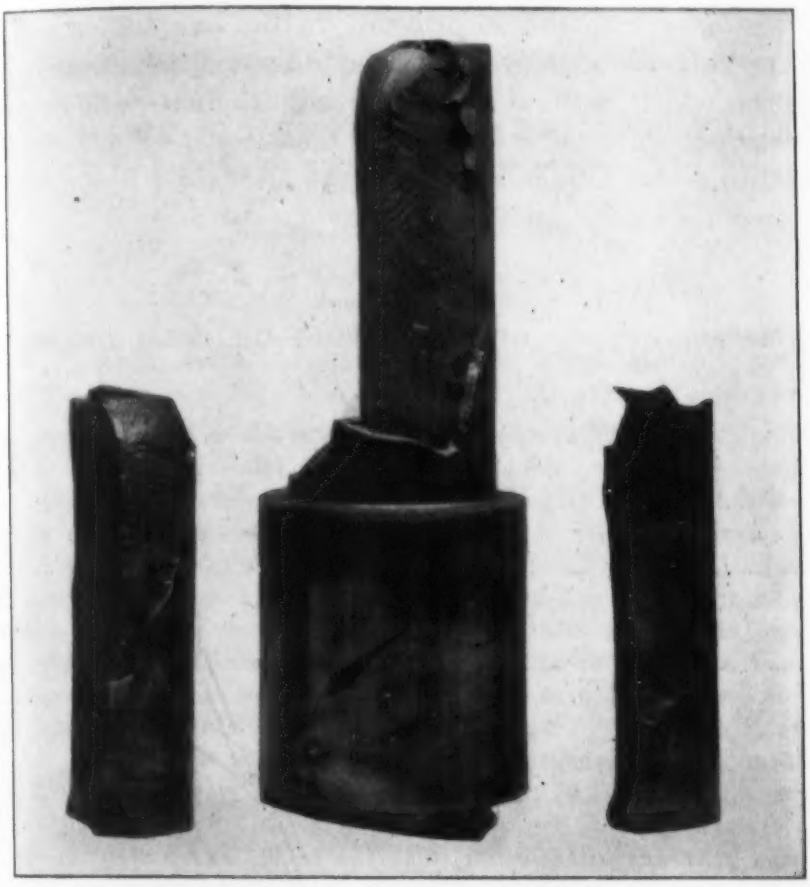


Fig. 1—Wrist Pin of 1.10 per cent Carbon Steel, Showing the Spalled-off Condition after Hardening.

in service, are undoubtedly what caused the peeling, having set up a progressive disintegration of the shaft to the point of final failure.

Heat Treat Error Discloses Reason for Peculiarity

It was found at the Bliss plant on one job, that steel which, according to factory instructions, if given a low anneal after forging, did not have physical properties called for by the maker for the steel after that treatment.

Through an error in not understanding instructions, the heat treating department gave the job the heat treatment specified by the maker, rather than to anneal it. The heat treatment error was discovered when the forging was sent back for machining.

It would not machine easily. Investigation disclosed the error and the shaft was then given the low anneal and proper physical properties obtained.

The answer to this is probably in the fact that the finishing forging heat was so high that it left the steel in a coarse-grained condition which the low anneal did not eliminate, and it required normalizing again before the low anneal could be effective. This normalizing was brought about by the accidental heat treat given it between forging and annealing.

DISCUSSION—EFFECT OF REHEATING ON COLD DRAWN BARS

(Continued from Page 716)

annealing. These annealings, made at temperatures of 1400 down to 1000 or 1100 degrees Fahr., would certainly have taken out any effect of acid brittleness. Still this carbon drill rod would show the same effect. In fact, I have some figures here which will show what was obtained on an experiment of that kind. The carbon drill rod was taken from stock, a material that had been cold drawn and polished and put in stock. I do not know how long it had been in stock or what time aging it had, but it had had some time. It showed a yield point of 58,000 pounds per square inch, a tensile strength of 96,000 pounds per square inch, and a Brinell hardness of 187. After subjecting this drill rod to an annealing temperature of 700 degrees Fahr., the yield point had gone from 58,000 to 77,000 pounds per square inch; the tensile strength had gone from 96,000 to 101,000 pounds per square inch, and the Brinell hardness, strange to say, increased from 187 to 207. Now, off hand, you would think that that was rather queer, that you could take a piece of what was soft tool steel and heat it up to 600, 700 or 800 and have it get harder, but apparently that was what happened. The increase in hardness was not very great, but there is some increase in hardness. This had probably had three or four drawings. The final draft was fairly light. It is annealed before the final draft.

DISCUSSION—INFLUENCE OF HEAT TREATMENT AND CARBON CONTENT ON THE STRUCTURE OF PURE IRON-CARBON ALLOYS

(Continued from Page 754)

paper, it seems that measurements on steel at elevated temperatures are prerequisite to such a conclusion.

As to Professor Boylston's suggestion that the tetragonal structure might account for the A_2 point, it should be borne in mind that Westgren found no change in the crystal structure of iron at the A_2 point. Therefore it would seem that, at least in the absence of carbon, the change at A_2 is not accompanied by a change in the distribution of the atoms.

Educational Section

These Articles Have Been Selected Primarily For Their Educational And Informational Character As Distinguished From Reports Of Investigations And Research

FACTS AND PRINCIPLES CONCERNING STEEL AND HEAT TREATMENT—Part VI

By H. B. Knowlton

Abstract

This article reviews briefly some of the points brought out by other writers concerning distortion, warping, and cracking, and brings out some of the practical applications.

The changes in shape, changes in volume, the effect of the composition of the steel, the temperature, the different methods of heating and of quenching are discussed.

Distortion, Warping and Cracking

IN the earlier articles of this series the simpler conditions of annealing, hardening and tempering were discussed. In the present article some of the difficulties arising in the hardening room will be discussed. Among the greatest of these difficulties are the warping, cracking and distortion, which frequently accompany heat treating operations. Obviously it is desirable to have a piece which is to be hardened pass through the hardening process without any permanent change in size and shape. It is needless to say that the cracking of a piece in the heat treating operation renders the piece useless for the service intended.

There are probably quite a number of factors which enter into distortion, warping and cracking. There has been much discussion on this subject, and apparently there is still much to be

[1]The first installment of this series of articles appeared in the March, 1925, issue of Transactions, the second installment appeared in the June, 1925, issue, the third installment appeared in the October, 1925, issue, the fourth installment appeared in the January, 1926, issue, and the fifth installment appeared in the April, 1926, issue.

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learned about it. Some types of distortion seem to be readily accounted for, but concerning others there is still room for argument. Even some of our best authorities express a doubt concerning the causes of some of the types of distortion.

The final dimensional changes which are produced by the heat treating operations may be divided into two classes: those which involve a change in volume, and those which involve a change in shape without a change in volume. In the latter type of distortion one dimension is increased and another decreased, but the volume remains the same as before heat treating.

Concerning the permanent changes in shape which are produced by heat treating, Keller[1] has offered a clear explanation, which seems to thoroughly cover many cases. He has analyzed the mechanical reactions which are produced by uneven heating and cooling, and has shown how such uneven heating and cooling cause the steel to alter its original shape.

It will be attempted herein merely to summarize briefly some of the points brought out by Keller and to discuss some of the causes of uneven heating and cooling in practical work. (We are taking the liberty of substituting examples used by Keller in some of his earlier talks for the ones given in his Cleveland Convention paper.)

When steel is heated it expands in all directions. Except, while passing through the critical points, the expansion is proportional to the temperature, the higher the temperature the greater is the expansion. Similarly, when a steel body cools it tends to contract in all directions. The amount of contraction during cooling from any given temperature down to room temperature is the same as the expansion caused by heating from room temperature up to that temperature. From this it might seem that heating and cooling should not cause any permanent change of shape. This would be practically true if the heating and cooling could be conducted in such a way that there would be no resistance to expansion or contraction in any direction.

Resistance to Heating and Cooling

If, during heating, the normal expansion in any one direction is hindered or resisted, an expansion of greater than the normal amount will be produced in some other direction. Similarly, if,

[1] Transactions, American Society for Steel Treating, Vol. IX, page 373, March, 1926.

during cooling, the contraction in one direction is resisted, there will be a greater contraction in some other direction. As Keller states, "a force follows the path of least resistance." Either of these conditions will produce a change in the final shape of the piece. For example, suppose that a bar having a square cross-section and whose length is not more than three times its thickness, is held by squeezing it endwise between the jaws of a heavy vise, and while thus held it is heated to a high temperature. The bar would naturally tend to expand uniformly in all directions, but the vise would prevent any lengthwise expansion. As a result the bar would bulge in the center. The result would be the same as though a heated bar were placed in the vise and then the vise jaws tightened, squeezing the bar shorter by an amount corresponding to the normal expansion. This action is a type of forging known as "upsetting." In the former case the bar "forged" or upset itself. If, while still held in the vise, the bar is allowed to cool to room temperature, it will contract in all directions and drop out of the vise. After heating and cooling in this manner the bar would be shorter in length but thicker in section in the central portion than it was before heating. If a very thin bar is held in the vise during heating it would buckle or bend sideways.

Similarly, if a heated bar were held by the ends during cooling, so that a contraction in length would be resisted, there would be greater than normal reduction of diameter in the central portion. The result would be the same as would be produced by pulling the bar. If the bar were made of a brittle material, it would probably crack in the center while cooling in the manner described. Thus, resistance to expansion produces compression, while resistance to contraction produces tension.

Causes of Resistance to Expansion and Contraction

When a piece of steel is heated or cooled absolutely uniformly there should be no resistance to expansion or contraction (except while passing through the critical ranges), unless the piece is acted upon by some outside force. Consequently, uniform heating and cooling should produce little or no permanent change in shape.

On the other hand, if a piece of steel is heated unevenly, the conditions and the results are quite the reverse. For example, if one spot in the center of a bar were heated while the rest remained cold, there would be a resistance to expansion in at least

one direction. The result would be similar to that produced by heating the bar in the vise. As the piece non-uniformly heated cools, the action is reversed and the cold portion resists the contraction of the part which was heated.

In general, it may be stated that uneven heating and uneven cooling bring about a resistance to expansion and contraction in certain directions and cause a change in the final shape. Keller cites numerous applications of this principle which will not be discussed herein. However, these actions deserve considerable thought and study. Doubtless the reader can think of applications to his own work.

Keller calls attention to another important fact which enters into distortion, that is, that steel is much stronger when cold than when hot. As a result, when a piece of steel is heated unevenly, it is the part which is heated first which is changed in shape by the resistance of the portion still remaining cold. Similarly, when the cooling is not uniform, it is the part which stays hot the longest which will be forged by the contraction of the first part to cool.

It cannot be said too emphatically that it is uneven heating and uneven cooling that is responsible for the greater part of the distortion or change of shape. It is not sufficient that the temperature of a tool be uniform at the time it is quenched for hardening. It must be heated uniformly from the start.

Effect of Volume Changes at the Critical Point

Another factor entering into distortion is the changes in volume which take place in steel when passing through the critical point. When a piece of steel is heated it expands steadily until the critical point is reached. At that point it stops expanding and contracts very slightly. As it is heated above the critical point it expands again. On cooling from above the critical point, steel contracts until the critical point on cooling is reached. At that temperature the steel stops contracting and may expand slightly. On cooling below the critical point the contraction is normal again. In some steels there are several critical points at which the expansion and contraction either stop or are momentarily reversed.

While these actions undoubtedly have some bearing on warping and distortion, it must be remembered that contraction at the critical point on heating and the expansion at the critical

point on cooling is very slight in comparison with the total amount of expansion and contraction which takes place during heating from room temperature to above the critical point, and cooling from that point back to room temperature. Consequently, it cannot be expected that a study of the changes taking place at the critical points will give us a complete explanation of warping and distortion. Uneven heating and cooling through other temperatures are as much or more responsible for the trouble.

Nevertheless, it is good policy to heat all steel parts very slowly while passing through the critical point. This is particularly true in the case of large pieces. If there is considerable difference between the temperature of the outside and the center of a block of steel during heating, the outer layers will reach the critical point first and will begin to contract, while the center portions are still expanding. When the outside has passed through the critical range it will again expand. At that time there will be another layer somewhere between the outside and the center, which will be at the critical point and which will, consequently, begin to contract while the outer layer and the center are both expanding. This action must, necessarily, cause severe strains. The ideal method of preventing this is to heat so slowly when approaching the critical range that the entire block from outside to center will pass through the range at the same time and, consequently, will expand and contract together.

Permanent Volume Changes

The changes produced by these distortion actions, as previously stated, are changes of shape rather than of size or volume. That is, if, after heat treating, it is found that one dimension of the piece has decreased, it will also be found that some other dimension has increased. There are cases, however, in which the volume of a piece of steel has been permanently changed by heat treating. These may probably be explained on the basis of some internal change in the structure of the steel. Such differences in structure are undoubtedly due to the changes which take place at the critical points, or to the prevention of the natural changes at these points by sudden cooling. It must be remembered that when steel passes through the critical point on cooling that it normally expands. If the cooling were sufficiently rapid to prevent internal changes from taking place it might be expected that some

of the expansion at this temperature would not take place. This would mean that the volume of the piece would be less after heating and quenching than it was before. Also as drawing or tempering allows some of the internal changes in structure to proceed it might be expected that the hardened piece should grow in volume during tempering. It is significant that in at least some cases such an increase in the final volume of the piece has been produced by drawing or tempering. In fact, with at least one kind of steel, the final size of the tool may be controlled by varying the drawing temperature.

Effect of Quenching Temperature

The exact temperature from which steel is quenched for hardening seems to have some effect upon the amount of distortion which is produced. Several[2] have reported that there is a definite temperature for quenching any kind of steel which will produce the minimum amount of distortion. This is generally given as a temperature slightly above the critical point. Although the writer has not been able to find the statement in print, he believes that a theory was advanced several years ago that the amount of expansion for each degree of increase in temperature of a steel body must be different above and below the critical point. This, coupled with the fact that steel contracts instead of expands while being heated through the critical point, would give an explanation of the fact that steel bodies of the same size and shape after similar hardening treatments, did not show the same amount of distortion. Sometimes the diameter was increased and sometimes it was decreased. However, the data presented by Harder, Dowdell, and Forsythe show the same rate of expansion per degree increase of temperature above and below the critical point. These data were obtained by accurately measuring the expansion of steel during heating. Consequently, it seems impossible to explain distortion on a basis of a difference in the rate of expansion at different temperatures.

Effect of Speed of Cooling

In general, it may be stated that the faster the speed of cooling, the greater will be the amount of distortion which may be

[2] Transactions, American Society for Steel Treating, Vol. IX, page 403, March, 1926.

expected. A piece which is heated and cooled slowly and uniformly should not show any distortion or change of size and shape, unless it was previously strained. Unfortunately, hardening of most kinds of steel necessarily involves rapid cooling. Oil quenching seems to produce less distortion than water quenching because the cooling speed is slower. It may be queried whether the excessive distortion sometimes produced by quenching from unusually high temperatures is not due to the more rapid cooling produced by the greater difference between the temperature of the steel and of the quenching bath. It may be open to argument as to whether the distortion produced by rapid quenching is due to the mechanical actions produced by the surface cooling faster than the center, or to the structural changes which are produced in the steel.

Effect of the Composition and Structure of the Steel

The chemical composition of the steel also has an effect on the amount of distortion produced by hardening. A steel body which does not expand or contract at all during heating or cooling should not suffer any distortion on heating and quenching. Such a steel would be said to have a "coefficient of expansion" of zero. Steels containing from 30 to 40 per cent of nickel have low coefficients of expansion and have found certain commercial uses on that account. However, these steels cannot be hardened. The point is, that the coefficient of expansion may depend upon the composition and be different for different steels. It would seem, therefore, that, other things being equal, the steels with lower coefficients of expansion would have an advantage over those having the higher coefficients of expansion.

Some of the alloy steels can be hardened by much slower quenching than that necessary in the case of plain carbon tool steel. Consequently, it should be possible to harden them with less distortion. Some of the oil-hardening tool steels are sold under such names as "non-shrinking" and "non-deforming" steels. For the same reason, steels which harden from comparatively lower temperatures are claimed to suffer less from distortion.

It is claimed by some that the "fiber" and structure play an important part in distortion. The amount of deformation is said

to be different, depending whether it is measured in the direction of the fiber or across the fiber.

Effect of Strain

It has long been known that a piece of steel which is under strain may warp or distort in some way on being heated. Sometimes cracking in hardening is due to previous strains. Forging, hardening, or any uneven heating or cooling, or mechanical treatment may set up strains. Even machining is said by some to cause strains. An interesting case was reported not long ago of a punch-press forming-die which cracked in hardening. It had been handled with the usual care in the hardening room and no particular reason could be found for its cracking. It was found later that, due to rush production, the die had been used in the soft condition for a short time prior to being sent to the hardening room. This use probably set up the strains which caused the cracking. It is good practice to anneal every piece of steel which is suspected of being in a strained condition, before attempting to harden it. Some favor reannealing after rough machining.

Examples of Distortion in Gear Hardening

The hardening of automobile gears is an example where the elimination of distortion becomes an important and difficult problem. Such gears must operate quietly. A plant in which the writer worked several years ago made a study of this problem. The gears in question were defective from three types of deformation: the webs were warped; they were "out of round"; or they increased or decreased in diameter. The latter point was proven by measurements of outside, pitch and root diameters. An increase in diameter was by far the more usual, although a decrease in diameter was not uncommon. Also many of the gears came out the right size.

These gears were made of S. A. E. 2315 (3.5 per cent nickel, 0.10-0.20 per cent carbon) steel. They were forged, annealed and finish machined before being sent to the hardening room for case hardening. The routine heat treatment consisted of carburizing at 1600 degrees Fahr., quenching in oil from the pots, reheating to 1310 degrees Fahr. in lead pots, quenching in water, and drawing to 375 degrees Fahr. in oil. In an effort to solve the distor-

tion problem, a series of tests were run, using a number of gears of the same size and design. Several variations from the standard treatment were tried. All of the gears were numbered, and their diameters were measured and recorded before and after each step of the case hardening process. Even the position of the gears in the carburizing pots and the position of the pots in the furnace was recorded, as it was thought that variations of the carburizing temperature might have a bearing on the problem. A number of gears were given each treatment, so that we should not be misled by experimental errors. It was hoped in this manner to arrive at some definite conclusions with regard to the cause of distortion and the methods of overcoming the difficulty. Unfortunately, however, the same treatments did not always seem to produce the same results. In general it was found that the higher quenching temperatures were more likely to produce distortion. Also water quenching seemed to be more harmful in this respect than oil quenching, but the results were far from consistent. The variation from the correct diameter was from —0.003 to +0.012 inch. Some of the gears came out the right size. It was interesting that the gear which showed the most distortion (+0.012 inch) and one of those which showed no distortion were next to each other in the carburizing pot, were reheated together on the same rack in the lead pot, and were quenched and drawn together. Why, then, was there so much difference in the distortion? The design and the treatment were the same for both gears. The question was not answered.

Summary of Distortion Principles

Whatever may be the complete explanation of warping, cracking and distortion, it may be briefly stated that these troubles are produced by nonuniform heating and cooling or by the steel being under strain. The exact temperature of heating for quenching may have some bearing on the problem. Cracking is caused by forces tending to produce a change of shape or size after part or all of the steel piece is in a hardened condition. Consequently, hardening cracks would not be expected in steel which have little or no hardening power. Similarly, quenching of tool steel from below the hardening temperature should not cause cracking, although it might cause a distortion of some kind. (The relation of

quenching temperature to cracking has been brought out by Honda.[3])

Practical Applications

Uniform Heating

It must follow from the foregoing that it is of utmost importance that steel parts be heated uniformly, if a change in shape is to be avoided. Absolutely uniform heating means not only that heat shall be absorbed by all surfaces at the same speed, but that the temperature of the outside and the center of the steel must be at all times the same. If the steel is heated so slowly that the heat is conducted to the center as fast as it is absorbed by the surface, then it can be truly said that the heating is uniform throughout. It is not always commercially practicable to heat steel so slowly, but it may be said that when distortions are encountered it is often found that slower heating is helpful, as it produces less difference between the temperatures of the surfaces and the center. It should be obvious that large pieces must be heated more slowly than small ones. In fact, in the case of very large pieces, such as die blocks, it is often advisable to place the pieces in a furnace which is below a red heat and raise the temperature gradually. The heating should be slow, particularly at the start, while the steel is cold and rigid. After the entire piece is red hot it may be heated somewhat faster, except while passing through the critical range. In the case of small pieces it may be possible to place them directly in a furnace which is at the hardening temperature without harmful results. However, it is good practice to at least warm even small tools before placing them in a hot furnace.

The use of a preheating furnace maintained at a temperature slightly below a red heat may prove quite beneficial when handling parts which are likely to warp, crack, or distort. This usually means additional expense. It depends upon the part to be hardened, whether such an expense is justified.

It is frequently possible to heat small tools slowly by placing them first in the front of the furnace near the door and then gradually working them back into the hottest zone. On the same principle there are continuous heating furnaces on the market in which the steel parts are slowly advanced from one end to the

[3]Transactions, American Society for Steel Treating, Vol. III, page 729, April, 1923.

other. The charging end of the furnace is comparatively cool, while the maximum temperature is reached at the discharge end.

It is also important that the steel parts should absorb heat on all surfaces at the same rate. When a piece of steel is placed on the hearth of a hot furnace, there is a tendency for the surface in contact with the hearth to heat very rapidly at first. This chills the hearth somewhat. Once chilled, the hearth may regain heat rather slowly. It sometimes happens that the top of the steel piece heats faster than the bottom which is in contact with the chilled hearth. If a "sharp" flame hits the steel it is obvious that uneven heating will result. It is sometimes possible to support steel pieces in the center of the oven so that they are heated almost entirely by the furnace gases or by radiation from the furnace lining. Such heating, when possible, should be more uniform, and, consequently, advantageous. In the case of small tools it is sometimes possible to produce fairly uniform heating by rolling them over during heating.

Heating by immersion in melted lead or melted salt has some advantages. As all of the surfaces of the steel piece are in contact with the melted lead they all absorb heat at the same rate by conduction. The objection to this method of heating is that it is often faster than may be desirable. In this respect lead is probably more rapid than melted salt. Due to the greater weight of the lead there is a larger *quantity* of heat in a pot of melted lead than in a pot of the same size containing melted salt at the same temperature.

Uniform Cooling

It is practically impossible in the case of most steels to produce uniform cooling and hardness. Rapid cooling is necessary in order to harden most kinds of steel, and rapid cooling means that the outside cools faster than the center, and that the thick sections cool slower than the thin ones. However, much of the warping and distortion may be avoided by making the quenching as uniform as possible. A well known rule in the hardening room is to quench thin sections vertically. If a long, thin piece is quenched horizontally it will warp. Some think this is because the bottom surface strikes the water first. This does not completely explain what happens. When a hot piece of steel is dipped in water, it causes the water touching the steel to be changed into steam. Naturally, the steam rises and more water rushes in

to take its place. Thus, when a long, thin piece is held horizontally during quenching the rising of the steam tends to hold the water away from the top surface while cold water is constantly rushing against the bottom surface. This is avoided by holding the piece vertically. Round bars have been successfully quenched horizontally by spinning them during quenching. This causes uniform quenching over the whole surface.

Keller has brought out that when one edge of a shear blade or similar tool is quenched, warping or cracking, or both, may result, due to the lack of uniformity of the cooling. Better results could be produced by holding the tool vertically and quenching all over.

Oil quenching has the advantage over water quenching in that it is slower and, consequently, more uniform. Of course, it is not possible to produce the desired hardness on all steels by oil quenching. There is a tendency, however, to substitute oil hardening steels for water hardening steels in the manufacture of certain parts which give distortion troubles. In a similar way the air hardening steels have an advantage over the oil hardening steels where they can be used.

Abstracts of Technical Articles

Brief Reviews of Publications of Interest to Metallurgists and Steel Treaters

THE NAVY AND THE STEEL INDUSTRY. By G. K. Spencer. In *Iron Age*, April 1, 1926, page 913. This article is the second of a series by the author setting forth the importance of the U. S. Navy as a factor in the development of the steel industry in this country.

In 1883 when the steel navy was under construction, the difficulty and expense of producing a stern frame of steel for the "Chicago" loomed large. This was accomplished in 1887, and marked the introduction of cast steel of good quality and in large sizes in this country.

With the development in castings came a similar one in forging methods and machinery. This gave an impetus to American manufacture and soon, with the navy in the lead, railroads adopted steel castings for locomotive frames and this was, no doubt, the beginning of their rapid development.

The author is of the opinion that the navy has been a potent factor in producing wealth, comfort and safety in America. The necessity for defense and consequently the building of large, strong and durable ships, aircraft, guns, etc., resulted in a development of the process of alloying steel with other substances and of the ingenious heat treatments of steel.

Steadily under pressure of the need for a better product, forged steel of great elastic limit and strength was produced.

It was found that acid open-hearth steel for high-grade forging for naval requirements was superior to basic steel. Lack of American ore for this purpose necessitated the opening of mines in Cuba and South America. The new steamship lines needed to bring the ore from the mines are a valuable addition to our merchant marine.

THE PRODUCTION OF COLD-DRAWN HOT-PRESSED PIPE UNIONS. By R. C. Knoll. In *American Machinist*, April 8, 1926, page 565.

This article describes the methods for making pipe unions and the sequence of operations required for making the nut from low-carbon skelp through the various processes to completion.

The author further describes the class of steel used, the pickling process, the dies for blanking and drawing, the hot-press forging and the preservation of the life of the dies. In connection with the heating of the shells for the hot-pressed forging he describes the type of furnace necessary to be used and that gas is the fuel used in this furnace, and further sets forth the advantages of heating the rear of the furnace to a higher temperature than the front, so that the shells may be heated gradually upon entering the furnace. Diagrams aid materially in showing the various operations neces-

sary in the production of this type of pipe unions. The author concludes his article by describing how the life of the dies may be prolonged.

INFLUENCE OF OXIDE-CONTAINING ADMIXTURES ON THE PHYSICAL PROPERTIES OF DINAS BRICKS. By K. Endell and R. Harr. *Transactions* of the Material-Committee of the "Verein deutscher Eisenhüttenleute."

Dinas bricks have about 2 per cent CaO, 1 per cent Fe_2O_3, 1 per cent Al_2O_3 and 96 per cent SiO_2. The authors cite a great number of researches, dealing with the question of the influence of admixtures; but it is not stated what amounts the impurities are necessary or which may be present in dinas bricks without impairing the properties.

To solve this question, oxide containing admixtures of CaO, Al_2O_3, Fe_2O_3 (2, 4 and 6 per cent) or of 2 or 3 per cent of two oxides at a time, as $Al_2O_3 + Fe_2O_3$, $Al_2O_3 + CaO$, Fe_2O_3, were added to silicia bricks.

These researches give the following results for the practice:

(a) The percentage of Al_2O_3 in burnt silica-stones should in no case exceed 1.5 per cent.

(b) A proportion of chalk up to 8 per cent altogether has no influence on the softening temperature under strain and furthers the transformation of quartz in trydimit.

(c) Increasing proportion of FeO favors the formation of trydimit in a high degree and has up to 4 per cent no influence on the softening temperature. For the use of such stones it is determining, whether they are stable when employed in a reducing atmosphere.

Dr. Hans Pollack.

VAST IRON ORE RESERVE IN SOUTH AMERICA, UNDEVELOPED. By Olin R. Kuhn. In *Iron Trade Review*, April 8, 1926, page 925.

The author is of the opinion that large deposits of high-grade ore are to be found in South America, and that vast undeveloped regions in the interior of this continent will yield a large tonnage of iron ore, perhaps the largest of any of the continents. The development of the iron and steel industries in other countries will cause these deposits to be placed on the market, and South America will become one of the largest exporters and consumers of this commodity. Though the area of South America is about twice that of the United States, its population is approximately but fifty per cent of that of the states.

While South America has high-grade ore, its lack of coal fields has retarded its growth. But a few coal mines exist and the coal does not coke well.

Foreign countries have sought to obtain possession of the iron ore lands in this southern continent. The Tofo mines in Chile are at present about the only ones in operation and the ore from these mines is sent to the United States.

Brazil, Peru and Chile are said to have the largest iron ore deposits and scattered through the other countries are smaller deposits. Those of Argentina are of inferior quality.

Argentina imports some half million tons of iron and steel products each

year, but no pig iron is produced. Practically the same condition obtains in Brazil.

Brazil comprises about half the area of South America and is said to have the largest supply of iron ore in the world, some seven and a half billion tons. Notwithstanding these rich deposits there are only three or four small blast furnaces in all Brazil. The ore deposits are controlled and financed mostly by foreign capital. The author describes the two types of ore found as magnetite and hematite, and is of the opinion that the latter is by far the most extensive. He further discusses their deposits and formations and thinks that the bedded ores, especially the hard, massive ores consisting of about 69 per cent iron and 1 per cent silica, and found in beds varying in thickness up to 450 feet by 3300 feet long, will ultimately place Brazil in a high position among the iron producing countries of the world.

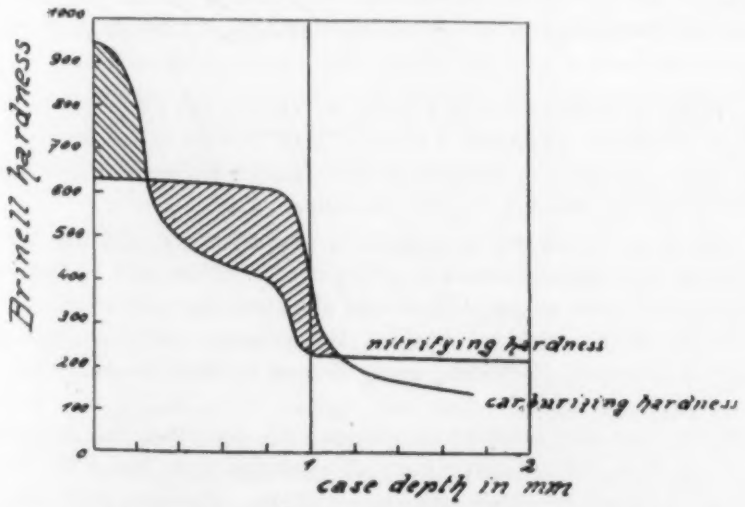
Though little, if any, Brazilian ore has been used in the United States, the writer is of the opinion that this rich ore, mixed with some of our ore of inferior quality, will be advantageous.

With improved transportation facilities and a supply of coal of a quality suitable for the production of iron, the continent of South America, in the writer's opinion, will one day be of vast importance.

THE NITRIFYING-PROCESS OF THE FRIEDR. KRUPP. By Dr.-Ing. Ad. Fry, Essen. *Maschinenbau*, Vol. 5, Copy 4, February 18, 1926, page 161-165.

This process, patented to the Friedr. Krupp, avoids the disadvantages of the carburizing process, as warping, distortion and cracks.

Machining of the parts, which are made from certain special steels, may be completely finished. Then the parts are treated in nascent nitrogen up to



1075 degrees Fahr. The depth of nitrifying depends upon the time during which the parts are at temperature. After this process they are slowly cooled outside the furnace. Quenching is unnecessary. The figure shows the hardness-depth curve of nitrified and carburized parts. The nitrified ones have a Brinell hardness from 900 to 1000 to a depth of 0.01 to 0.02 millimeters, then

the hardness decreases rapidly. The carburizing process gives a surface of about 630 Brinell to a depth of 1 millimeter or more. This enables the carburized parts to endure a greater surface pressure than the nitrified pieces, fitted for a pressure of about 7000 kilograms per square centimeter. Nitrified parts which are exposed to the dust of the streets, as crankshafts, etc., are more wear-resistant than carburized parts. The hardness of nitrified parts is retained up to 930 degrees Fahr.; at this temperature the nitrified surface is destroyed by scaling. The nitrifying hardness is only obtained with certain special steels, manufactured by the Friedr. Krupp A.-G., Essen. These steels have the same mechanical and machining properties as chromium and nickel-chromium structural steels. Some of the uses for nitrified steels are: gears, bolts, spindles, bearing parts, axle shafts, parts of typewriters and calculators, gages, etc.

Finally the author gives figures for the cost of nitrifying—parts and comparisons of cost between the carburizing—and the nitrifying process.

The purpose of the nitrifying process is not to replace the carburizing process but to amplify it.

Dr. Hans Pollack.

DILATOMETRIC INVESTIGATION OF THE A^3 and A^4 TRANSFORMATIONS IN PURE IRON. By Seikichi Satô. Reprinted from the Science Reports of the Tôhoku Imperial University, Series I, Vol. XIV, No. 5. Sendai, Japan, December, 1925.

The author sets forth the arrangement and method of his experiment. He used a Rosenhain carbon ring electric furnace which worked in a vacuum. The specimens were cylindrical rods made of armco iron. He then explains the various steps in the experiment and sets forth the results obtained. A comparison of the results of experiment with that of X-ray analysis is given and the author concludes with a short summary of the findings of his investigation.

ON THE WIDMANNSTATTEN STRUCTURE IN IRON-CARBON AND IRON-NICKEL ALLOYS AND IN METEORITES. By Tutom Kasé. Reprinted from the Science Reports of the Tôhoku Imperial University, Series I, Vol. XIV, No. 5. Sendai, Japan, December, 1925.

The author describes an investigation conducted by him for the purpose of reproducing the Widmannstätten structure in carbon and nickel steels and to explain the probable origin of the said structure in meteorites.

The writer endeavored to obtained the structure with various steels by cooling under different conditions, using forged Swedish carbon steel. Forty-five experiments were made.

He divides meteorites into two groups and describes the constituents of each. The analyses of schreibersite and rhabdite and the difference in the nickel content in these two elements are set forth. He next gives the chemical composition of camacite and taenite in tables and discusses their differences. A magnetic analysis with a meteorite specimen was then made and the findings are given in detail. An examination of the thermal expansion with a dilatometer was conducted by the experimenter and the hardness of camacite and taenite was determined by scleroscope test. The author also enumerates the

change of microstructure in the meteorite under various heat-treatments and then discusses the effect of impurities on the Widmannstätten structure. Concluding the author observes that long exposure to high temperatures and moderately rapid cooling is effective in obtaining the well-developed Widmannstätten structure usually found in meteorites. He is of the opinion that long exposure to high temperature and rapid cooling is the probable reason for said structure in meteorites.

His text is further elucidated by twenty-five photographs showing the various structures of the meteorite under different conditions.

PROCEEDINGS IN PLASTIC DEFORMATION. By Dipl.-Ing. H. Hoff and Dipl.-Ing. G. Sobbe, Düsseldorf. *Maschinenbau*, Vol. 5, Copy 3, February 4, 1926, page 109-112.

The authors explain the property of plasticity. Emanating from results, gained in the practice, they give a brief summary of the present theories of the processes involved in the upsetting of plastic bodies.

Dr. Hans Pollack.

PICKLING OF IRON WITH HYDROCHLORIC ACID AND SULPHURIC ACID. By Dr.-Ing. H. Bablik, Brunn a. G., Austria. *Stahl und Eisen*, February 18, 1926, page 218-222.

Removing of scale consists of two partial reactions; the merely chemical solution of the ferrous oxide (FeO) by the acid and the blow off of the scale from the iron by the developing hydrogen. Using hydrochloric acid for pickling, the first reaction is greater than the second, but when sulphuric acid is used the second reaction is more effective. The chemical reactions are accompanied by an electrochemical reaction. The solution of the FeO is thereby facilitated, as it has been previously reduced. The intensity of pickling increases with the temperature of the pickling liquid and with the concentration of the pickling acid. Sulphuric acid has a maximum at 25 per cent H_2SO_4; in cold liquids the effect of pickling is very unimportant. The economy of "Vogels" pickling-admixture is shown and the author states its effect produced by capillar-active forces.

Dr. Hans Pollack.

HEAT CONTROL LIMITS DETERIORATION OF LONG LIFE MOLDS. By H. A. Schwartz. In *Foundry*, February 1, 1926, page 93.

This article is the second of a series, and in it the author discusses mold deterioration and its various phases. He is of the opinion that fluctuations and unevenness of temperature distribution are more conducive to permanent deterioration of molds than high steady temperatures. The writer claims that by the proper regulation of heat and disposition of the excess heat, permanent mold temperature can be steadily held at any predetermined limit and hence the mechanical and chemical disintegration of the molds can be largely eliminated.

The author sets forth the process which he thinks solves the difficulty encountered in the deterioration of mold life. He also sets forth the temperature ranges and their limits. Weight, size, and shape of the castings are important factors which must be taken into consideration in this process

of heat stabilization. Increasing cooling area of the mold is also important and the writer discusses this phase at some length.

The inventor continues with an explanation of stabilizing temperature and heating and cooling effects are considered.

Methods of producing castings with either hard or soft characteristics are next given consideration.

The results of a number of tests showed that the temperature range was small even over an extended period of time for castings weighing as much as 35 pounds. The ideal heat absorbing medium is taken into account by the writer, and he is of the opinion that the heat absorbing fluid acts as a carrier for heat units and endeavors to substantiate his claim.

He says in part: "All this mold temperature regulation and stabilization is only made possible by the use of a heat absorbing fluid having certain necessary physical and thermal properties capable of coping with the unnatural temperature conditions encountered in permanent mold casting."

Concluding, the author describes the control of the absorbing fluid flow by thermostatic devices which regulate and stabilize the mold temperature.

PLASTIC FORMATION—A CONTRIBUTION TO THE TECHNOLOGY OF METALS. By P. Schweissguth, Dortmund. *Maschinenbau*, Vol. 5, Copy 3, February 4, 1926, page 105-109.

The chief methods for the plastic formation of metals are: forging, rolling, drawing and extruding. The similarity between the rolling mill and the forge is given. The author explains the plasticity of a material. Finally he gives the classification of forges and the subgrouping of them.

Dr. Hans Pollack.

MODERN FORGING - MACHINES. By A. Georg, Düsseldorf. *Maschinenbau*, Vol. 5, Copy 3, February 4, 1926, page 114-116.

In this paper the author shows the range of application of the horizontal forging machine. He describes the operation of the so-called "two point system," that is patented to the Hasenclever A.-G., Düsseldorf. Finally he outlines the claims of the practice on forging-machines. *Dr. Hans Pollack.*

ON THE RELATION BETWEEN THE EQUILIBRIUM DIAGRAM AND THE MAGNETIC SUSCEPTIBILITY IN BINARY ALLOYS. By Hikozo Endo. Reprinted from the Science Reports of the Tohoku Imperial University, Series I, Vol. XIV, No. 5. Sendai, Japan, December, 1925.

The author states that few experiments have been made to establish "the relation between the magnetic susceptibility and the equilibrium diagram in the case of the diamagnetic and paramagnetic alloys." He made this experiment to find this relationship, and possibly to revise the diagram. The author enumerates the systems of alloys used in the experiment and their relations.

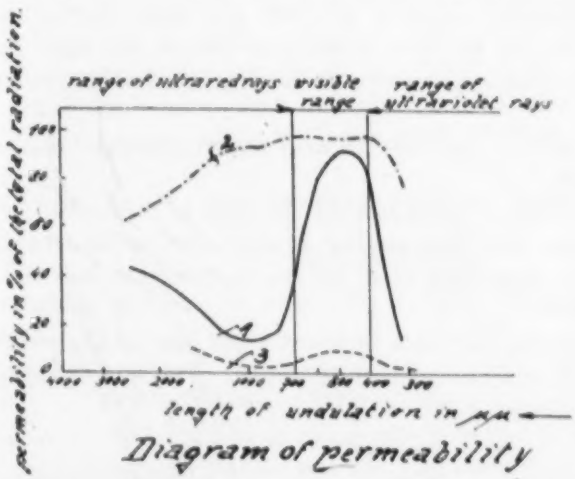
SUNSHINE, CLEANLINESS AND GOOD WILL AS MANUFACTURING ASSETS. By John H. Van Deventer. In *Industry Illustrated*, March, 1926, page 24.

This article is one of a series which describe via words and pictures

visits to noted plants. The author stresses the importance and value of a clean workshop and maintains that an attractive environment makes for better production both in quality and quantity. He is of the opinion that a contented mind makes for high ideals and accuracy, and that the workman who expresses joy in his work is an artist. He says that "good housekeeping" is essential in every plant and makes for greater efficiency and larger profits.

PROTECTION OF HEAT FOR THE EYES. By R. Linke, Jena. *Stahl und Eisen*, February 11, 1926, page 192-193.

By the action of rays of heat derangements of the visual power are called forth; the unfortunate effect of such rays is not observed in a trice, but little by little. The retina is sensible to length of undulation from 397 to 723$\mu\mu$; that is the so-called visible range. Below 397$\mu\mu$ there is the range of the ultra-violet rays; from 723 to 8000$\mu\mu$ is the range of the ultra-red rays or rays of heat. Both of these rays, but above all, the ultra-reds, exert a great sensitive stimulation on human organs. The so-called "glass-maker cataract" is exclusively caused by the action of the ultra-red rays. The optical workshop of Carl Zeiss, Jena, has manufactured sight from heat preserving glasses. The figure shows the properties of the glass employed for these


range of ultrarednys
visible range
range of ultraviolet rays
permeability in % of the total radiation
length of undulation in μμ
Diagram of permeability

spectacles. Curve 1 shows that only a small rest of the radiation passes through the preserving glass in the injurious range from 700-1500$\mu\mu$. In the visible range of the spectrum there is no absorption as the glass is only softly colored. In comparison with that curve 2 shows the absorption by the usually used, colorless glass. Very dark glasses of the same color as of that one in curve 1 are used in welding plants and at melting-furnaces; the optical properties of these glasses are shown in curve 3. Finally a detailed description of the construction of the spectacles is given. *Dr. Hans Pollack.*

THE THEORY AND PRACTICE OF ROLLING STEEL. By Wilhelm Tafel. In *Iron Trade Review*, April 1, 1926, page 864.

This article is a continuation of one heretofore presented and sets forth the calculations of rolling speed of steel and the various roll diameters and their speeds.

DELVING INTO METAL STRUCTURES. By J. R. Vilella. In *Iron Age*, March 25, 1926, page 834.

Chromic acid plus hydrochloric acid as an etching medium for certain copper alloys is taken into consideration in this article. Grain structures and alloying aggregations are shown.

Uniform etching is obtained by constantly moving the specimen in the solution and immediately washing it in a current of hot water.

THE QUALITATIVE AND ECONOMICAL IMPORTANCE OF ACID ELECTRIC-FURNACE STEEL. By Dr.-Ing. A. Müller-Hauff, Bismarckhütte, Oberschlesien. *Transactions* of the Steel-Works-Committee of the "Verein deutscher Eisenhüttenleute," Düsseldorf. *Stahl und Eisen*, February 18, p. 213-218; March 4, p. 289-294.

The acid electric steel process consists essentially of the melting down of the charge with following self acting deoxidation and degasification. Oxidizing of carbon takes place much slower than in the basic furnace because the viscous slag prevents strong boiling. The FeO, necessary to oxidation, is taken away from the bath by the acid slag. Oxidizing of carbon takes 5 to 10 times longer than in the basic furnace. For this reason the charge is made as low in carbon as possible. During the melting down the oxidation of manganese ordinarily amounts to 50-80 per cent, that of chromium to 10-25 per cent; the loss of tungsten is smaller than in the basic furnace. Temperature is of particular importance; it must give an activity as great as possible to the slag.

Then the author describes an acid electric furnace charge by the aid of a material-balance.

In the metallurgy of acid steel the slag is of no less importance than in the basic process. The high quality of acid steel is fixed by the quality of the end-slag, almost free from iron, by the temperature and the time of reaction on the steel bath.

The melting slag amounts to about 4 per cent of the weight of the charge; its color is black, not transparent, glasslike. The slag is easily fusible and has the following average composition:

	per cent		per cent
SiO_2	50-60	MnO	15-20
P_2O_5	0.03-0.05	Cr_2O_3	3-5
Al_2O_3	4-5	MgO	0.10
Fe_2O_3	0.10	S	0.03-0.05
FeO	15-20		

After removing the oxidizing slag, the deoxidizing slag is made of chalk and sand; the content of chalk is about 20 per cent. The slag absorbs all oxides and becomes thereby more basic and less reductible. Adding of fresh sand and increasing of temperature increases the reductibility of the slag. The content of SiO_2 is on an average 60-70 per cent. The endslag is glasslike, its color depends upon the amount of dissolved metal oxides and lies between dark-green and light-blue.

Reduction of SiO_2 is the most remarkable of all reactions in the acid electric furnace. This reduction is influenced by the chemical composition,

the degree of liquidity and the temperature of the slag. The reactions of the reduction are:

$$SiO_2 + 2\ Fe \rightleftarrows Si + 2\ FeO$$

$$SIO_2 + 2\ C = 2\ CO + Si$$

The reaction according to the first equation from the right to the left takes place especially in the basic open-hearth furnace and partly in melting down on the acid hearth. The reaction from the left to the right goes on at the surface of contact of steel and hearth or steel and slag. The second reaction should be very effective, because the formed CO is escaping; thus the reaction is only possible from the left to the right. But the fact that the taking up of silicon in low carbon steels may be accomplished in the same time as in high carbon steels proves that the second reaction is only of secondary importance; for the iron, present in a great excess, possesses a greater reductivity than carbon. The dependency between the taking up of silicon and reacting surface is shown. Using a crucible, this dependency is the greatest; therefore the crucible has the greatest deoxidizing effect.

The lining of the acid electric furnace and the durability of it are described.

Amount of phosphorus and sulphur in acid electric steel

It is impossible to removed phosphorus and sulphur; therefore the charge must be chosen with an adequate low content on these constituents. With an increasing of both from the ferro-alloys must be calculated. To investigate the influence of phosphorus on the tensile strength and on the impact values the author tested steels with more than 0.03 per cent phosphorus. The unfavorable influence appears only when the percentage of phosphorus amounts 0.066 per cent.

In the basic electric furnace process desulphurization takes places according to the reaction:

$$FeS + CaO + C = Fe + CaS + CO$$

In the acid electric process there is only a little decrease during the oxidizing period.

Sulphur escapes as SO_2:

$$FeS + 2\ FeO = 3\ Fe + SO_2$$

But an intensive desulphurization is not possible as the FeO is intensively combined with the acid slag and its concentration in steel is unimportant.

Desulphurization according to the reaction:

$$3\ FeS + 2\ CaO + CaC_2 = 3\ Fe + 3\ CaS + 2\ CO$$

$$\text{or } FeS + CaO = CaS + FeO$$

is verified but only of little influence.

Influence of the acid hearth on texture

Acid carbon tool steels have a quenching range from 750-850 degrees Cent., that means they undergo, quenched from a temperature of that range, only a little loss of tenacity. The author performed bending tests and shows hardening fractures of tool steels with 0.65-1.35 per cent carbon which prove the great flexibility of acid electric steels, heat treated within a range up to 120 degrees Cent.

Physical examination and comparison of basic and acid steels

The author investigated basic open-hearth and basic and acid electric steels

of approximately the same chemical composition. The electric steels are superior to the open-hearth steels. Among the electric steels, the acid steels are superior to the basic steels.

Finally the author discusses the scope and the economy of the acid electric steel process.

Dr. Hans Pollack.

THE NAVY AND THE STEEL INDUSTRY. By G. K. Spencer. In *Iron Age*, April 8, 1926, page 983.

This concludes the series of three articles on the relationship of the navy department and the steel industry in this country.

The article sets forth that one of the greatest features of the Act of 1882, which provided for a new navy to be built of steel, was the specification that the steel must be of domestic manufacture. This resulted in a decided growth in engineering and the development of the various processes for the making of high grade steel which would meet the rigid requirements of the navy. Prior to this time shipbuilders were using wrought iron and steel imported from England because the United States had not developed the necessary skill and machinery to produce even small castings. This marked the beginning of the industrial research and development in the steel industry. Cooperation of manufacturers with the naval department in producing steel which satisfied the rigid specifications has also resulted in the solution of problems which arise in every-day production, for they are similar, except that the navy need not show tangible profit on its investments. Better products have resulted in increased manufacturers' earnings.

The author describes the evolution of naval machinery, the extensive inspection service in both raw and finished products and the endeavor to establish uniformity and the national standardization of design. Much time and energy are expended in seeking the proper use of metals and alloys and the proper heat treatment of materials. New alloys are constantly being sought that will reduce the weight and size of machinery, so that more fuel may be carried and the field of action of the vessel increased. This is of vital importance.

SOMETHING ABOUT HAMMER-FOUNDATIONS. By A. Schneider, Düsseldorf. *Maschinenbau*, Vol. 5, Copy 3, February 4, 1926, page 116-119.

The author contributes to the clearing up of the indistinct conditions in hammer foundations and to the influence of the weight of anvil-beds.

Dr. Hans Pollack.

EMPLOYMENT OF SILICATED AND NON-SILICATED STEEL FOR THE MANUFACTURE OF SEAMLESS TUBES BY THE MANNESMANN —AND TUBE-ROLLING-PROCESS. By Dr.-Ing. Conrad Wolff, Mülheim-Ruhr. *Transactions* of the Steel-Works-Committee of the "Verein deutscher Eisenhüttenleute."

The steels used for these investigations had the following chemical composition: Non-silicated, 0.09-0.16 per cent carbon; 0.38-0.52 per cent manganese; silicated, 0.10-0.15 per cent carbon; 0.50 per cent manganese; 0.18-0.25 per cent. silicon.

By means of rolling tests with ingots of different diameter, the author

shows the unfavorable influence effected by blow-holes in non-silicated steel; then he shows that there is no stretching-out and welding of steel by using the Mannesmann-process as it was accepted in former days. The author states that for seamless-tubes manufacturing by the two processes it is recommendable to use silicated steel which is killed and free from blow-holes. The question whether non-silicated steel is qualified for tube manufacturing is not determined.

Dr. Hans Pollack.

APPLYING STELLITE TO MACHINE PARTS, TOOLS AND DIES BY BLOW TORCH. In *Iron Trade Review*, April 1, 1926, page 861.

Stellite became a commercial product in 1914 and is being used extensively in the metalworking industries. Its hardness at a bright red heat and its resistance to severe abrasion makes it valuable for metal cutting. Acids and chemicals have little, if any, effect on it. It requires no heat treatment and takes and retains a high silver-white polish and it is also nonmagnetic. The author sets forth its chemical constituents and the process of manufacture. Its lack of machinability bars its use for machine parts or complete tools.

Depositing a coating of stellite to metal parts by the use of the oxy-acetylene flame provides a way of salvaging worn out parts lacking in size and the reinforced surface results in increased life. This can be done at small cost. Stellite may be applied to nearly every metal and the method of doing it is described. Technique in using the blowpipe is required and speed is necessary. Blowholes will not appear if the surface is clean. Certain precautions to be observed are enumerated. The base metal should be ground clean. The method of building up a die corner is explained and illustrated.

DELVING INTO METAL STRUCTURES. By J. R. Vilella. In *Iron Age*, April 1, 1926, page 903.

The author sets forth the two reagents most commonly used for etching aluminum and its light alloys and discusses them at some length. He shows undeveloped crystal formations and constituents which the etching medium brings out by means of photographs. He also takes up the likelihood of a combination of reagents of class 1 and class 11 resulting in a new reagent and its capabilities of differentiating between compounds and also developing the microstructure.

The author then sets forth the means of identifying the various constituents of aluminum alloys by the action of the reagent and concludes his article by showing the ability of the reagent to differentiate between iron, nickel and manganese aluminide, for which test three alloys were prepared.

FIXING OF JOB-RATES AND CALCULATION OF SELF-COSTS IN COLD-ROLLING MILLS. By Dr.-Ing. A. Pomp, Düsseldorf. *Stahl und Eisen*, February 11, 1926, page 183-186.

The author gives a short description of cold-rolling practice and shows that fixing of job-rates offers some difficulties because the dimensions of the bands, to be rolled, vary within large bounds. Accordingly to the measurements of the band the diameter of the rolls must be chosen of various sizes.

The number of turns of the rolls differs accordingly to the diameter. But even rolls of the same diameter have sometimes different numbers of turns according to the material to be rolled, and to the accuracy wanted of the band. To act according to these different circumstances in fixing the job-rates the author develops an equation by which the tasks of the bureau of wages, of the management and of the sales department are positively simplified.

Dr. Hans Pollack.

LIFTING INDUSTRY'S BURDENS. By F. C. Eibell. In *Industry Illustrated*, March, 1926, page 27.

The author sets forth the tremendous growth in the application of electricity to industry from 1876 to the present day.

The improvement in the electric hoist was the result of the demands made by modern industry for strength, speed and safety, etc. The electric hoist is a great asset today in every field. It is especially valuable in foundries, and today the utility of these hoists is appreciated by every man in the foundry. It relieves man from the drudgery of lifting and makes production on a large scale and in heavy tonnage possible. This ingenious method of letting gravity do his work for him is but another instance of the application of Nature's laws in the physical world. Thus man by the use of his brain saves his body and another step in progress is made.

Many interesting pictures show the various ways in which electric hoists are used.

DISCUSS CUPOLA MALLEABLE IRON. By D. Wilkinson. In *Foundry*, February 1, 1926, page 102.

The two processes of manufacturing malleable cast iron are set forth by the author. He then describes the cupola practice of melting iron and the points to be heeded in this process.

Since white iron is more difficult to handle than gray, because of its higher contraction and liability to shrinkage and cracking, the precautions necessary to be taken are enumerated.

The packing of the castings in the annealing pot is of importance, and the procedure in this respect is definitely described.

Uniform temperatures in the annealing oven during the entire process is imperative to good results but difficult to obtain. The author is of the opinion that the fire should be started slowly (overheating produces bad annealing) and that some method of determining the temperature should be employed, and states that his preference is the use of the radiation pyrometer.

He continues with a discussion of the chemistry of the product and the part that hydrogen plays in the process and the ultimate result obtained.

ASCERTAINMENT OF THE WORKING-TIME OF FORGINGS. By Kaessberg, Lehmann and Oeser. *Maschinenbau*, Vol. 5, Copy 3, February 4, 1926, page 119-122.

In this paper the authors show how the difficult ascertainment of the heating time can be removed by developing a furnace chart which is fully described. By means of such a chart the ascertainment of the working time can be simply, promptly and reliably made. *Dr. Hans Pollack.*

MAKING HIGH GRADE STEEL—IX. By John A. Coyle. *Iron Trade Review*, April 8, 1926, page 929.

This article deals with the steels used in the making of mechanical tools for ploughing or turning over the soil for the purposes of aeration and the absorption of water.

The author gives a brief description of the various types of ploughs used and their development from primitive times to the present.

Continuing, he gives the analyses of plow steel and is of the opinion that the production of soft center plow steel is dependent upon unusual skill. The open hearth, electric and crucible melting processes are then set forth and he describes the latter method at some length.

The great variety of shapes required is a serious handicap and results in losses to the manufacturer. Cooperation between the maker and user would result in economies, is the opinion of the author.

FIREPROOFING STRUCTURAL STEEL. By R. M. Norton. *Canadian Machinery*, April 1, 1926, page 28.

The author sets forth in this article that steel becomes capable of carrying greater loads as the temperature increases and that it will support a load 15 per cent greater at about 600 to 700 degrees Fahr. than at normal temperature. This is not true of other structural materials.

Incombustibility is not the criterion of efficiency of construction. The material must be impervious to high temperatures. Rate of absorption and radiation of heat are important factors to be taken into consideration in the erection of a firesafe building. A protective coat of air is imperative. Efficiency, not cost, must be considered. A maximum resistance to the destructive forces must be a paramount consideration. Economy demands that this be done at the least possible cost. The writer discusses this phase of the subject and also gives the temperature curve showing the unit strength per square inch for various temperatures. He takes up the matter of maximum of expansion and shows the variation of the rate of expansion. He then discusses the tendency to distortion when subjected to heat. He is of the opinion that no material equals air for the distribution of heat and that unbroken air space is a protection against fire. The best protective material is plaster on metal lath, as this has a tendency to distribute the heat equally.

He concludes his paper with a description of how the joists carry their designed load and why this method of construction is advantageous not only in its power to resist the destructive force of fire, but in its ability to carry heavy loads.

The Question Box

A Column Devoted to the Asking, Answering and Discussing of Practical Questions in Heat Treatment — Members Submitting Answers and Discussions Are Requested To Refer to Serial Numbers of Questions

QUESTION NO. 179 *What is the difference between grinding cracks and grinding checks?*

QUESTION NO. 180. *Explain the effect of decarburization in grinding.*

QUESTION NO. 181. *How may a pyrometer be checked by means of carbon tool steel?*

QUESTION NO. 182. *What indication, if any, is given in the quenching of tool steel if the steel is quenched while going through the critical range?*

QUESTION NO. 183. *What effect, if any, have the additions of alloys on the internal stress of tool steels?*

QUESTION NO. 184. *What precaution should be observed in quenching tool steels containing chromium?*

QUESTION NO. 185. *What precaution should be observed in designing such a tool?*

QUESTION NO. 186. *Why should marking dies be rubbed with emery cloth before using?*

QUESTION NO. 187. *What causes the carbonaceous deposit on steel parts when quenched in oil from temperatures about 1600 degrees Fahr.? How can this be eliminated? Do all oils have the same effect in the same degree?*

QUESTION NO. 188. *What causes the scaling on the inside of holes of piston pins when heated in a Hoskins electric pusher type furnace? Does the sulphur content of the steel have any marked effect?*

QUESTION NO. 189. *What is the McQuaid-Ehn test and what are its merits in selecting steel for carburizing?*

QUESTION NO. 175. *How long should high speed steel tools be left in the high draw?*

QUESTION NO. 174. *How long should high speed steels stay in the preheat?*

QUESTION NO. 173. *To what temperature must high speed tools be permitted to cool before drawing and why?*

QUESTION NO. 172. *Can you quench and draw high speed steel in one heating operation?*

QUESTION NO. 171. *What is the hardness of carbon steels at elevated temperatures such as 400 to 1000 degrees?*

QUESTION NO. 170. *Why do you get a low Rockwell reading on Stellite?*

QUESTION NO. 169. *What is the hardness of high speed steel at elevated temperatures such as 400 to 1000 degrees?*

QUESTION NO. 168. *Why is a high draw beneficial to high speed steel?*

QUESTION NO. 167 *Is deep acid etching as satisfactory for high speed steel as for carbon steel?*

ANSWER. By H. O. Stahl, metallurgist of the Strom Steel Ball Company, Oak Park, Illinois.

Deep etching high speed steel will give just as satisfactory results as deep etching carbon steels. However, the high speed steel will require more time in the acid to give satisfactory results.

QUESTION NO. 166. *What is a satisfactory mixture of acid to use in the deep acid test and also the temperature of the liquid and the time the piece should be immersed?*

ANSWER. By H. O. Stahl, metallurgist of the Strom Steel Ball Company, Oak Park, Illinois.

The best deep etch test solution to use is 1:1 hydrochloric acid diluted from the concentrated acid with distilled water. The acid should be kept constant at 190 degrees Fahr. The time element will depend entirely on the condition of the steel. Hardened steel will require a longer etch than annealed steel of the same composition.

QUESTION NO. 165. *What importance should be placed on the carbon content of high speed steel?*

QUESTION NO. 159. *What is the explanation for the retarding effect on corrosion of small amounts of copper in low carbon steel?*

QUESTION NO. 158. *What is the present recognized cause for the "transverse fissure" as occasionally found in rails?*

QUESTION NO. 157. *Does 0.070 to 0.090 per cent phosphorus in low carbon basic open hearth steel tend to prevent "stickers" in the rolling of sheets? If so, what is the explanation for such a tendency?*

QUESTION NO. 156. *What is the cause of "stickers" in the rolling of sheets from low carbon, basic open hearth steel sheet bar?*

ANSWER. By F. G. White, metallurgist, National Enameling and Stamping Co., Inc., Granite City, Ill.

Phosphorus or silicon in low carbon steel sheets make the steel much more difficult to weld. An addition of either of these elements in the steel will tend to reduce the possibility for these sheets to "stick" or weld during hot rolling. However, phosphorus of 0.07 to 0.09 per cent also tends to make the steel "cold short," which destroys it for deep drawing work. Silicon of 0.06 to 0.10 per cent is likely to cause the sheet to blister seriously, especially if the silicon is not properly added.

QUESTION NO. 154. *What are the advantages of nickel steel versus chromium-nickel steel for carburizing?*

ANSWER. By T. H. Wickenden, development and research department, International Nickel Co., New York City.

There are certain characteristic differences in the properties of a straight-nickel and chromium-nickel steel for carburizing which will make their selection largely dependent upon the type of work under consideration.

In order to limit the discussion, I will confine my remarks to a comparison of the carburizing properties of low chromium-nickel steel SAE-3120 versus 3.5 per cent nickel-steel, SAE-2320.

The 3.5 per cent nickel steel can be heat treated at temperatures about 50 degrees Fahr. lower than are required for chromium-nickel steel. This is, of course, an advantage in tending to produce less warpage and less rapid deterioration of the hardening equipment, especially if the heating is done in lead or salt baths. The 3.5 per cent nickel-steel also has a wider temperature range between the AC_1 and AC_2 critical points than the chromium-nickel steel. This wider range permits of a wider variation in the hardening temperature used with nickel steel over the chromium-nickel steel and still keeps the core free from brittleness. It is possible to secure a higher core strength and hardness without danger of brittleness in the nickel steel. This is a particular advantage in gears which are subject to high tooth pressures which may result in cracking of the case due to flow of the soft core material.

The carbon penetration of the chromium-nickel steel is more rapid than in the nickel steel. A higher carbon content is also produced in the case which will result in a slightly higher hardness. However, unless the carburizing temperature is closely regulated, it will work to a disadvantage in producing a cementite network in the case with the attending danger of exfoliation. Most carburized parts require grinding after hardening. Experience has shown that a straight nickel steel is less sensitive to grinding cracks than a chromium-nickel steel. This is undoubtedly interconnected with the above characteristics.

The 3.5 per cent nickel steels will stand the prolonged heating of carburizing with less injurious effect than the chromium-nickel steel. As a result, the straight nickel steel can often be used satisfactorily with a single quench, while the chromium-nickel steel should always have a core-refining operation to avoid brittleness.

From the above characteristics I believe that, in general, it has been the experience of most metallurgists that the 3.5 per cent nickel steel is an easier steel to handle in the hardening room to produce the desired properties.

QUESTION NO. 142. ***What is the consensus of opinion of the cause of blisters in low and high grade steel sheets?***

ANSWER. By F. G. White, metallurgist, National Enameling and Stamping Co., Inc., Granite City, Ill.

Blisters in sheet steel are due to partially welded ingot blow holes which become small flat pockets in the sheet after rolling. Hydrogen penetration of either acid or water slowly penetrate the outer layer of steel, and with the addition of heat cause the two layers of metal to separate. In rimming steel these blow holes attain much greater size than in "killed" steel, and if not welded together in the rolling operation, will become large blisters.

QUESTION NO. 138. ***Is the electrolytic pickling process being used to show up defects in steel bars? If so, how does it compare with the regular pickling processes?***

Below is given a series of questions and a resumé of the answers which were formulated at the April meeting of the Hartford Chapter. It should be

remembered that the answers are the opinions of those who entered into the discussion and may or may not be the final answer to the point involved.

QUESTION. What is a suitable test to apply to a carburizing box before installing it in service?

ANSWER. It is difficult to make a satisfactory test of a carburizing box before placing it in service, but much easier to tell if it was a good box after it has been through service. Boxes are usually examined for visible defects and sometimes a chemical analysis is made to determine if the alloy being paid for is received.

QUESTION. What is the best method of preparing local carburized work for preventing copper plate from touching surfaces desired hard?

ANSWER. A very good method is to japan the surfaces desired hard by painting on liquid japan, baking it, and then copperplating the cleaned work. The copper will not adhere to the japanned parts, and in later carburizing the japan is burned off readily, allowing the carbon to penetrate at the proper places. Although not strictly answering the question, a common method of securing the same result is to copper plate the article after partial machining and then finish machining the parts desired hard.

QUESTION. Is copper plate always satisfactory in preventing carburizing?

ANSWER. No. The copper deposit must be firm and adhering and of dense structure. To secure this, the work must be thoroughly cleaned and the copper deposited from a cyanide bath at room temperature with a high current density. The thickness of copper required for complete protection depends upon time and temperature at carburizing. For carburizing, say, 3 hours at 1650 degrees Fahr., a deposit of the proper structure of 0.002 to 0.003 inch is generally sufficient. Carburizing compounds energized with sodium salts will generally attack the copper deposit and cause penetration of carbon where not desired. Barium energized compounds are sometimes used satisfactorily and bone black most always so.

QUESTION. Does case hardened steel lose its hardness when reheated to around 400 degrees Fahr., and, if so, why?

ANSWER. This operation represents a regular tempering, and as such should leave the steel in a condition that it can be just touched with a file.

QUESTION. What makes lead stick to polished steel at 1600 degrees Fahr. when hardening in lead?

ANSWER. All agreed that lead does adhere to polished surfaces more than to those in a rougher condition. No reason for this effect was brought forth at the meeting, but it has since occurred to the present writer that since molten lead does not ''wet'' steel and due to capillary action the minute depressions in the ''rough'' steel repel the lead from the steel at these points, thus keeping the lead and steel from an intimate contact as when the steel is highly polished and free from small depressions. The ever present impurities in the lead can then more readily cause the adherence in rough steel than in polished steel. Suggestions for securing less adhering of lead were to preheat at about 1100 degrees Fahr. and quench in brine from the hardening heat. A coating of oil on the work will also sometimes stop sticking. It was also pointed out that it should seldom be necessary to heat-treat polished material.

QUESTION. What is the effect of variation in annealed structure on the depth of penetration and warpage when hardening?

ANSWER. One large manufacturer of tools stated that completely spheroidized steel hardens deeper and with less warpage than a similar steel in the lamellar pearlitic condition. The latter takes a longer time at a higher temperature to bring about the same result. Other investigators have found the opposite to be true so that it was conceded that the method of heat treatment, class of tools, and composition of steel probably varied the desirable condition of the steel.

QUESTION. Is it true that steel contracts while passing through the critical range?

ANSWER. Yes. All steels show a definite contraction of volume when entering the critical range and a re-expansion when the transformation or solution of carbides is complete. The amount of contraction is different for various types of steel. In general the alloy steels, particularly the "non-shrinking" type, show the greatest contraction. In the plain carbon series the medium carbon steels show greater contraction than either the high or low carbon steels. Use of this phenomenon is made use of in the "dilatometric" method of heat treating. The changes in volume are caused to operate signals to advise the operator of the proper time to quench the steel.

QUESTION. Which die blocks are most satisfactory, those heat treated before or after sinking?

ANSWER. As a general rule, small blocks may be sunk before heat treatment, while large ones are best heat treated by the die block manufacturer and then sunk by the user. Local facilities and use will also influence the procedure.

QUESTION. What is the mechanism of the iodine etch?

ANSWER. It acts like a weak acid in attacking the steel.

QUESTION. What influence does size and shape of the piece have on the Rockwell Hardness reading? Also, how does the condition of the surface affect this value?

ANSWER. Scale should preferably be removed so that the hardness test will be on the sound metal. The proper anvil should always be used to give firm support to the work; for odd shaped pieces it is sometimes necessary to design special anvils to accomplish this. On very thin stock, particularly in non-ferrous material, it is sometimes necessary to use penetrators larger than the usual 1/16 inch ball, lighter loads, or both, to prevent the hardness reading from being influenced by the supporting anvil.

QUESTION. Is a v-block the proper type of support to use in testing round pieces under a Rockwell or Brinell machine?

ANSWER. The v-block is perfectly satisfactory if it is constructed so as to give rigid support to the work under test.

QUESTION. How would you obtain the best possible steel together with the best heat treatment for a particular job?

ANSWER. Large concerns can determine the best steels and best heat treatments by conducting extensive experiments and research to determine these facts. Specifications are then written and inspection tests made to see that

(*Continued on Page 38, Adv. Sec.*)

Reviews of Recent Patents

By
NELSON LITTELL, Patent Attorney
475 Fifth Ave., New York City
Member of A. S. S. T.

1,568,271, **Process for Treating Metals and Composition Therefore, David H. Crosser, of Chicago, Illinois, Assignor to Chicago Crucible Company of Chicago, Illinois, a Corporation of Illinois.**

This patent describes a process primarily for treating cast iron, whereby it may be purified and alloyed with other metals to give the desired physical characteristics. The purpose of the invention is to avoid the lack of homogeneity in cast iron which often results when an attempt is made to make additions in the ladle, or even where ferrosilicon or ferromanganese is added in the cupola, as either of these methods is likely to result in segregation of the modifying elements. According to the process of the invention, a small amount of the modifying element, in finely pulverized state, is mixed with a comparatively large amount of ceramic binder such as clay or the like, to form briquettes, in which the clay is much in excess of that necessary for binding the particles, and acts largely as a dilutant for the modifying element. These briquettes may then be charged into the cupola and distributed through the charge in such a way that upon melting, uniform distribution of the modifying ingredient is obtained.

1,571,290, **Quenching Bath, William J. Merten, of Pittsburgh, Pennsylvania, Assignor to Westinghouse Electric and Manufacturing Company, a Corporation of Pennsylvania.**

It is the object of this invention to provide a quenching bath which will quickly and uniformly cool the heated articles in a manner to eliminate soft spots or hair-like cracks in the article. The inventor states that the formation of a thin film of gas in the ordinary quenching bath causing ununiform cooling is the cause of soft spots and hair-like cracks heretofore developed, particularly in the heat treatment of steel tools. He, therefore, provides a quenching bath which dissolves any adhering salt from the heating bath and prevents the formation of vapor, gas or oxide films of low heat conductivity on the surface of the casting when it is quenched. The preferred quenching bath contains approximately 48 per cent water, 24 per cent sodium chloride, 16 per cent lime and 12 per cent sodium cyanide. The bath is agitated to keep the lime in suspension. A steel article when quenched in this bath shows no oxidation and the article retains its original lustre and is free from soft spots and hair-like cracks.

1,572,155, **Pickling, H. S. Marsh and Ralf S. Cochran, of Youngstown, Ohio, Assignors to American Copperas Company, of Youngstown, Ohio, a corporation of Delaware.**

These inventors have discovered that the mottled and darkened appear-

ance on the surfaces of rolled steel sheets and plates, etc., is due to the presence of non-ferrous metals, chiefly copper, and to some extent arsenic and lead, which are electrodeposited upon the surface of the steel in the pickling bath. The copper is due probably to the increased copper content in scrap steel. The mottled and dirty appearance may be avoided in the pickling by the generation in the pickling bath of sufficient quantities of sulphuretted hydrogen to form insoluble sulphides with the non-ferrous metals. In the practice of the invention, the pickling acid is placed in a suitable tank or container and iron sulphide is introduced which reacts with the acid to produce sulphuretted hydrogen, which reacts on the salts of the undesired metals to form insoluble sulphides. The supply of iron sulphide is maintained in the pickling vat when the steel sheets and plates are pickled, electrodeposition of non-ferrous metals is avoided and the sheets come from the vat with bright clean surfaces.

1,572,179, Steel Manufacture, T. J. Bray, Jr., of Youngstown, Ohio.

This patent describes the process of scavenging molten steel in the mold after it has been deoxidized to as great an extent as possible in the furnace. The inventor uses approximately one-half pound of sodium carbonate per ton of steel. The carbonate when introduced into the mold eliminates growing of the ingot in the mold, reduces or substantially eliminates blow holes and produces an ingot having fewer seams, scabs or blisters and having a more dense top so as to reduce the amount of cropping necessary.

1,572,487, Aluminum-Copper Alloy.

1,572,488, Aluminum-Silicon Alloy, Zay Jeffries, of Shaker Heights, and R. S. Archer, of Lakewood, Ohio, Assignors to Aluminum Company of America, of Pittsburgh, Pennsylvania, a corporation of Pennsylvania.

These patents describe the production by heat treatment of aluminum copper alloys having a tensile strength of approximately 50,000 pounds per square inch and an elongation of 8.5 per cent and in the case of chill castings, having a tensile strength of 54,000 pounds per square inch and an elongation of 18 per cent. The preferred alloy contains copper 4 per cent, magnesium less than 0.3 per cent, iron not in excess of 0.25 per cent and the remainder aluminum, together with silicon which is always found as an impurity. The alloy is poured into a chill or sand mold and after solidification, the castings are heated to and maintained at a temperature of 500 to 540 degrees Cent. for a sufficient length of time to cause the $CuAl_2$ network surrounding the aluminum rich constituent to go into solution into the aluminum rich constituent. The time for this transformation occupies from seven to forty-eight hours, depending upon whether a chill or sand casting is being heat treated. After the heating period, the castings are quenched in water and may be artificially aged by heating immediately to a temperature of 100 to 150 degrees Cent. for one hour. A chill casting is preferable to sand casting because of the fine grain and improved physical properties which make the castings more amenable to heat treatment.

In the second patent, the alloy used contains 3 to 10 per cent silicon, 2 to 5.5 per cent copper and 5 to 15 per cent zinc. The castings from this

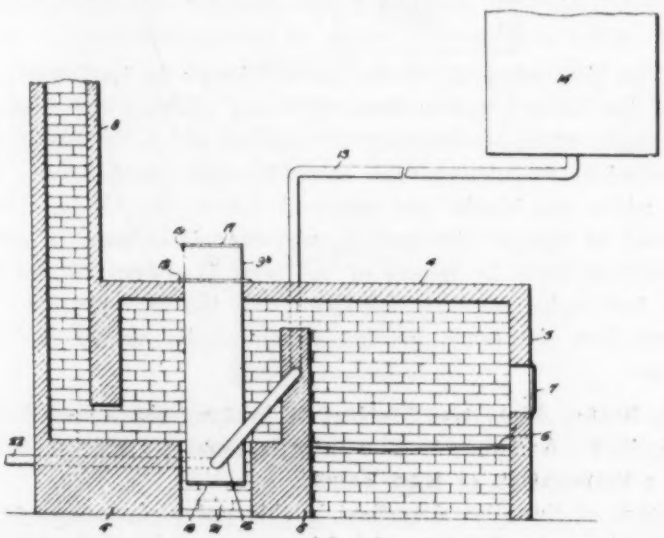
alloy are subjected to substantially the same heat treatment and quench as described above.

1,572,503, **Composition of Matter, Aladar Pacz, of Cleveland Heights, Ohio, Assignor, by Mesne Assignments, to Aluminum Company of America, a corporation of Pennsylvania.**

This patent describes an aluminum silicon alloy having special properties for die-casting. Ordinarily the presence of silicon in substantial amounts in an aluminum alloy is objectionable because of its tendency to segregate and cause large crystals, thereby weakening the alloy. If, however, the alloy of aluminum containing from 1 to 20 per cent of silicon is cast under pressure, as by die-casting, segregation is substantially overcome, the metal flows more freely into the mold, the castings are less likely to crack and warp and by the use of such an alloy, the die-casting process may be extended to much larger articles than heretofore. Other ingredients may be added to the aluminum silicon alloy without departing from the invention. The aluminum silicon alloy without other ingredients produces a casting having a high degree of lightness, tensile strength and ductility.

1,572,600, **Process of Annealing Iron Articles, H. T. Grafton and C. W. Weesner, of Warren, Ohio.**

It is the purpose of the invention to purify producer-gas in such a way as to reduce the carbon dioxide and oxygen content so that when used for annealing steel plates, the gas will have no oxidizing properties and blued

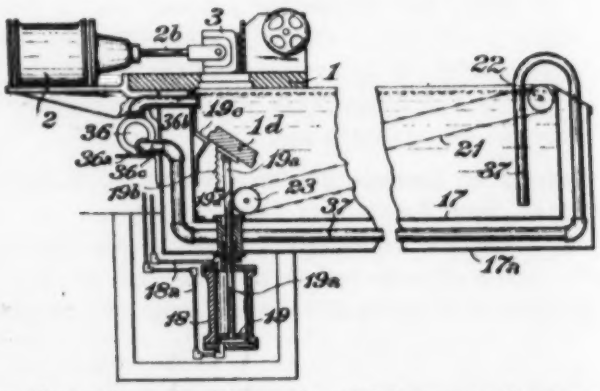


and stained plates will be avoided. The producer-gas is purified by conducting the gas from the storage reservoir 14 to a preheater 15, which is located in the fire wall 5 in the furnace 1. The preheated gas is then introduced through the pipe 16 into the purifying chambers 9a and 9b where it passes through a porous path of purifying medium, such as charcoal, the purifying chambers and contents being heated by the combustion gases from the fire chamber 4 of the furnace 1. This treatment, which is carried out at above 500 degrees Cent., eliminates the moisture in the producer-gas by a

combination of the oxygen of the moisture with the carbon in the charcoal, producing free hydrogen, and reduces the carbon dioxide to carbon monoxide, producing a gas having only reducing properties. The inventor claims the process of annealing iron articles by the use of purified producer-gas substantially free from oxygen and containing insufficient moisture to stain the iron articles.

1,572,639, Spring Forming Machine, T. F. Buckley, of Scranton, Pennsylvania.

This patent describes a spring-forming machine in which the heated spring blanks are bent to shape between the movable cross head 3 and the fixed abutments on the table 1 by means of the pressure cylinder 2 and the piston 2b. The portion 1d of the table 1 is tiltably mounted on the piston rod 19a of



the piston 19 so that when the piston is withdrawn to its lower position, the portion 1d of the table 1 moves downward and striking the abutment 19c is tilted at an angle of approximately 45 degrees so as to deflect the formed spring blanks when released by the movable cross head 3 onto the endless conveyor 21, where the blanks are conveyed out of the oil bath 17. The oil bath 17 is used to temper the springs and the oil is kept in circulation to maintain a uniform bath by means of the pipe 37, pump 36 and return pipe 36b, whereby the cooled oil is withdrawn from the rear portion of the tank and introduced into the front portion to force the heated part of the oil toward the rear.

1,572,744, Nickel Alloy and Method of Making the Same, P. D. Merica, of New York, N. Y., Assignor to The International Nickel Company of New York, N. Y., a corporation of New Jersey.

The inventor of the alloy described in this patent has discovered that the addition of aluminum to nickel or nickel-bearing metals, such as Monel metal, produces an alloy having a high tensile strength and highly resistant to erosion and corrosion, and therefore particularly valuable in steam turbine bladings and similar locations. The alloy is manufactured by deoxidizing molten Monel metal or molten nickel by the use of magnesium and mixing the deoxidized nickel-bearing metal with molten aluminum by pouring the nickel-bearing metal onto the aluminum. The mixing produces an evolution of heat which raises the temperature of the ladle

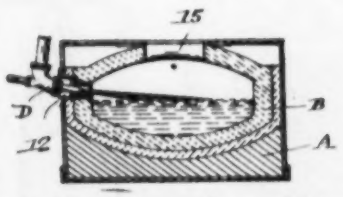
and may be taken advantage of by allowing the molten alloy to stand from three to five minutes to give the impurities an opportunity to rise to the surface and separate from the metal. The cleaned metal is then poured into ingots and reduced to shapes by any desired process. The addition of the aluminum increases both the hardness and tensile strength of the metal and the best mechanical properties are obtained with aluminum between 3 and 5 per cent, although the aluminum is effective in amounts between 1 and 10 per cent of aluminum.

1,572,848, **Removal of Oxides from Ferrous Metal, Rudyard Porter and J. C. Whetzel, of Pittsburgh, Pennsylvania, Assignors to American Sheet and Tin Plate Company, of Pittsburgh, Pennsylvania, a corporation of New Jersey.**

This patent describes a method of removing oxides from ferrous metals, especially from annealed stainless steel and particularly for removing the oxide or scale which resists the ordinary acid pickling bath. The process described provides for immersing the oxide coated sheet in a strong alkaline solution, such as sodium hydroxide, preferably heated to about 235 degrees Fahr. Subjecting the oxide coated sheet to this solution for about one hour breaks down the resistance of the oxide to the acid and when subsequently pickled in the ordinary acid pickling bath, the oxide or scale is completely removed.

1,573,004, **Method of Manufacturing Open Hearth Steel, J. D. Jones, of Sault Ste. Marie, Ontario, Canada, and E. E. Litz, of East Chicago, Indiana.**

This patent describes a method of manufacturing open hearth steel wherein the surface of the metal in the crucible B in the open hearth furnace A is subjected to an impinging action of flames projected at a high velocity from the nozzles D. Preferably three such nozzles spaced at equal distances around the furnace are used and the flame jet is directed downwardly against the

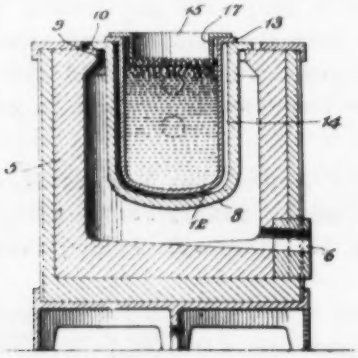


surface of the metal so as to keep the surface of the bath at a high temperature and prevent the creation of insulation, such as by the slag, between the heating medium and the bath.

1,573,535, **Pot or Crucible, A. E. Bellis, of Springfield, Massachusetts, and C. S. Collins, of New York, N. Y., Assignors, by Mesne Assignments, to the Bellis Heat Treating Company, of New Haven, Connecticut, a corporation of Connecticut.**

This patent describes a pot crucible for holding a fused salt bath for the heat treatment of metals, the pot being constructed so as to resist the oxidizing and acid action of the salt at high temperatures. The apparatus comprises an ordinary furnace 5 in which is suspended the outer shell 8 of the crucible made of metal, graphite or other refractory material and an inner body 12 of wrought iron or steel, supported by a flange 13 on the top of the shell 8

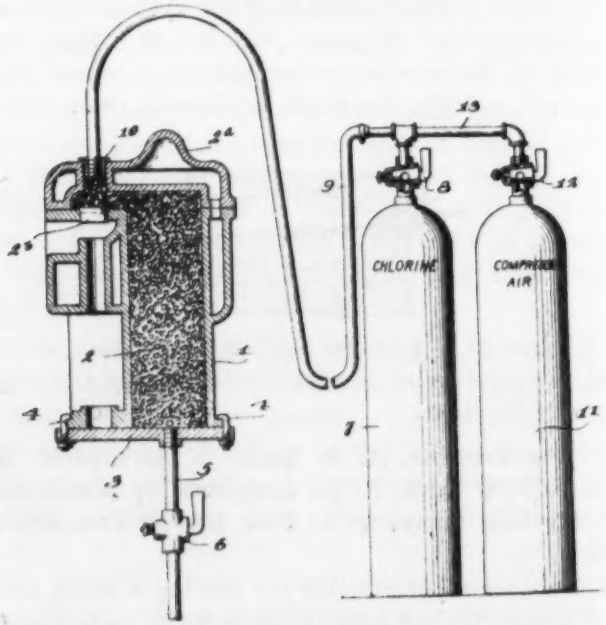
The space 14 between the inner and outer shell permits expansion and contraction of the inner shell relative to the outer shell and protects the inner shell from the action of the furnace gases. The sealing ring 15 rests upon



the top of the inner shell 12 and has a depending flange dipping into the salt bath providing an air space 17 around the top of the shell 12, which protects the shell from the oxidizing action of the air above the bath.

1,573,784, Process of Tempering Metals and Other Materials, J. W. Van Meter, of San Rafael, California.

This patent describes a process and apparatus for tempering metals, such as the internal combustion engine cylinder 1, wherein the cylinder is packed with an initially inert compound 2 comprising saw-dust, 1 pound; iron filings, 2 pounds; sodium cyanide, ½ pound; hydrocarbon oil, ½ pound.



The cylinder is sealed at the lower end by means of the plate 3 and hooks 4 and chlorine gas from the pressure tank 7 is introduced to the pipe 9 and the spark plug opening 10 into the compound 2 which reacts with the evolution of heat, and which quickly heats the inner wall of the cylinder to the

(Continued on Page 839)

News of the Chapters

STANDING OF THE CHAPTERS

IN the April issue of TRANSACTIONS appeared the relative membership standing of the 28 chapters of the Society as of February 1, 1926, and as of March 1, 1926. The tabulation which appears below shows the relative membership standing of the chapters on March 1, 1926, and April 1, 1926.

Standing as of April 1, 1926

GROUP I	GROUP II	GROUP III
1. Detroit (383)	1. Hartford (132)	1. Tri City (64)
2. Cleveland (367)	2. Golden Gate (128)	2. Los Angeles (64)
3. Philadelphia (354)	3. Lehigh Valley (117)	3. New Haven (58)
4. Pittsburgh (314)	4. Syracuse (99)	4. Washington (57)
5. Chicago (303)	5. Milwaukee (94)	5. Worcester (56)
6. New York (245)	6. Cincinnati (77)	6. Schenectady (50)
7. Boston (230)	7. St. Louis (72)	7. Rochester (49)
	8. Indianapolis (70)	8. Rockford (47)
	9. Buffalo	9. Toronto
	10. North-West	10. Providence
		11. Springfield

Standing as of March 1, 1926

GROUP I	GROUP II	GROUP III
1. Detroit (374)	1. Hartford (131)	1. Tri City (62)
2. Cleveland (363)	2. Golden Gate (120)	2. Los Angeles (62)
3. Philadelphia (328)	3. Lehigh Valley (111)	3. New Haven (59)
4. Pittsburgh (313)	4. Syracuse (97)	4. Worcester (54)
5. Chicago (294)	5. Milwaukee (89)	5. Washington (53)
6. New York (239)	6. Cincinnati (76)	6. Rochester (49)
7. Boston (230)	7. Indianapolis (71)	7. Schenectady (48)
	8. St. Louis (70)	8. Rockford (48)
	9. Buffalo (57)	9. Providence (43)
	10. North West (49)	10. Toronto (40)
		11. Springfield

GROUP I—Philadelphia again shows a larger gain than any other chapter in this group, closing the month with a net gain of 26 members, which places them securely in position 3, being 40 members ahead of Pittsburgh and right on the heels of Cleveland and Detroit. Chicago and Detroit both showed a net gain of 9 members for the month, while New York kept up its steady progress with a net gain of 6 for the month. Boston holds its own.

GROUP II—Golden Gate closed up the gap between position 1 and 2 until at present Hartford leads by only 4 members. Lehigh Valley showed a gain of 6 members and gives indications of passing both Hartford and Golden Gate and heading Group II. Milwaukee is making constant progress, having had a net gain of 5 members last month. Indianapolis slipped up and keeps position 8, right on the heels of St. Louis in 7.

GROUP III—Washington had a net gain of 4 members last month, and is now occupying position 4, but 7 members behind the leader of the group. Rochester remained stationary, but removed from 6th to 7th place. Toronto with a gain of 2 members and due to the loss of one by Providence, exchanges places with Providence and now is in position 9.

In March, 141 new members were added to the rolls, while 49 were lost by non-payment of dues, death and resignations, leaving a net gain of 93.

Since September 1, 1925, to April 1, 1926, there has been a net gain of 444 members, or 13.2 per cent. The membership to date is 3808.

In order to give chapter officials an opportunity to observe the gain made by their chapters since September 1, 1925, to April 1, 1926, the standing of the chapters is given in a different form. The net increase in the chapter's members together with the percentage of gain is indicated.

The second chart shows the arrangement of all of the chapters in the order in which the net gain in membership places them.

The last chart shows the chapters arranged according to the percentage of gain from September 1, 1925, to April 1, 1926.

Group I	September	April	Net Gain	Per Cent Gain
Detroit	376	383	7	2.0
Cleveland	324	367	43	13.3
Philadelphia	256	354	98	38.3
Pittsburgh	295	314	19	6.5
Chicago	263	303	40	15.2
Boston	215	230	15	7.0
New York	209	245	34	16.3
Group II				
Hartford	121	132	11	9.1
Golden Gate	88	128	40	45.5
Lehigh Valley	101	117	16	15.8
Syracuse	74	99	25	33.8
Milwaukee	71	94	23	32.5
Cincinnati	74	77	3	4.1
St. Louis	59	72	13	22.0
Indianapolis	53	70	17	32.1
Buffalo	52	59	7	13.5
North West	43	50	7	16.3
Group III				
Tri City	65	64	—1	—1.5
Los Angeles	60	64	4	6.7
New Haven	56	58	2	3.6

Group III (Continued)	September	April	Net Gain	Per Cent Gain
Washington	48	57	9	18.8
Worcester	47	56	9	19.1
Schenectady	51	50	—1	—1.9
Rochester	59	49	—10	—17.0
Rockford	42	47	5	11.9
Providence	39	42	3	7.7
Toronto	39	42	3	7.7
Springfield	30	29	—1	—3.3

NET GAIN IN MEMBERSHIP—SEPTEMBER 1, 1925, TO APRIL 1, 1926

1. Philadelphia ..98	9. Indianapolis ..17	17. Detroit 7
2. Cleveland 43	10. Lehigh Valley.16	18. North West .. 7
3. Chicago 40	11. Boston 15	19. Rockford 5
4. Golden Gate ..40	12. St. Louis 13	20. Los Angeles .. 4
5. New York 34	13. Hartford 11	21. Cincinnati 3
6. Syracuse 25	14. Washington .. 9	22. Providence ... 3
7. Milwaukee 23	15. Worcester 9	23. Toronto 3
8. Pittsburgh ...19	16. Buffalo 7	24. New Haven .. 2

NET LOSS IN MEMBERSHIP—SEPTEMBER 1, 1925, TO APRIL 1, 1926

1. Rochester 10	3. Schenectady .. 1
2. Tri City 1	4. Springfield ... 1

PERCENTAGE GAIN IN MEMBERSHIP—SEPTEMBER 1, 1925, TO APRIL 1, 1926

	per cent		per cent		per cent
1. Golden Gate	45.5	9. New York	16.3	17. Providence	7.7
2. Philadelphia	38.3	10. North West	16.3	18. Toronto	7.7
3. Syracuse	33.8	11. Lehigh Valley	15.8	19. Boston	7.0
4. Milwaukee	32.5	12. Chicago	15.2	20. Los Angeles	6.7
5. Indianapolis	32.1	13. Buffalo	13.5	21. Pittsburgh	6.5
6. St. Louis	22.0	14. Cleveland	13.3	22. Cincinnati	4.1
7. Worcester	19.1	15. Rockford	11.9	23. New Haven	3.6
8. Washington	18.8	16. Hartford	9.1	24. Detroit	2.0

PERCENTAGE OF LOSS IN MEMBERS—SEPTEMBER 1, 1925, TO APRIL 1, 1926

	per cent		per cent
1. Tri City	1.5	3. Springfield	3.3
2. Schenectady	1.9	4. Rochester	17.0

BOSTON CHAPTER

THE April meeting of the Boston Chapter was held at the River Works of the General Electric Company, at West Lynn, on Friday, April 2, 1926. The visitation started promptly at 1:30 p. m. and included all of the departments especially interesting to steel treaters. In the forge shop, the large steam and drop hammers were in full operation on the usual line of

heavy and light forge work. At the steel foundry, heats were tapped from both the electric furnace and the open hearths, and those who were interested in bronze and aluminum castings had an opportunity to see a large variety of work being molded, poured and cleaned. A few of the party took advantage of the invitation to visit the gray iron foundry where melting operations and the new battery of large molding machines were observed.

At the heat treating department, the new electric heat treating furnace, as well as the oil fired car-bottom furnace, and other large and small annealing and carburizing furnaces were all in operation and Stanley P. Rockwell, of Hartford, Connecticut, gave a very interesting and successful demonstration of the dilatometer hardening tools.

Other departments visited were the press room, where conveyor and lighting systems for efficient punch press work were demonstrated; the gear department, where machining and gear hardening were shown; and the chemical laboratory, where physical, chemical and microscopical tests were made.

The works closed at 4:30, after which a demonstration of street lighting and traffic control was run simultaneously with the American Brass Company's film, "From Mine to the Consumer."

Two hundred and thirty-one members and guests attended the turkey supper in the main dining room at six o'clock, at which Mr. N. J. Darling, manager of the river works, gave an address of welcome, including in his remarks a brief outline of the shop committee, bonus system, welfare work, etc., in effect at the river works. The report of the secretary followed, giving a summary of the March meeting, the nominations for the election of officers on May 7 and the names of the nine new members elected since the last meeting.

After a few words, humorous and otherwise, by A. H. d'Arcambal, metallurgist of the Pratt & Whitney Company of Hartford, regarding the Spring Sectional Meeting at Hartford, Connecticut, Prof. George B. Waterhouse told the Chapter a few of his experiences on his recent trip to the Krupp Works at Essen, Germany, speaking particularly of their development of rustless iron and steel.

Mr. Darke then introduced Mr. F. R. Palmer of the Carpenter Steel Company at Reading, Pennsylvania, who, after he had expressed his appreciation for a second invitation to speak before the Boston Chapter, proceeded to deliver his talk on "Giving Tool Steel a Chance." Mr. Palmer divided his talk into four parts—design, tool-making, hardening and grinding. Several slides were shown of tools of intricate sections which had been successfully hardened after holes had been drilled the length of the tool to balance the sections. He cautioned against the use of square corners and recommended fillets in all keyways, stating that one of the foremost manufacturers of cutters charge a premium when square cornered keyways are specified. In cases where prick punch-marks have been used in laying out the work or where hobbing or other unusual operations, which tend to strain the steel, have been resorted to, he advised the tool maker to inform the hardener, so that the tool may be annealed to remove strains before hardening.

In the hardening room he made a plea for suitable furnace equipment and accurate pyrometers and emphasized the necessity for slow and thorough heating to a point above the critical temperature, cooling in water, oil or both to a temperature low enough to insure maximum hardness, keeping in mind getting the tool into the tempering furnace or bath with the least possible delay. Several slides were shown to demonstrate the methods of obtaining the proper atmosphere in the heating furnace to prevent surface decarburization, one of the tests being that of placing in the furnace a piece of wood, which, if the fuel and air are in the proper proportion, will not burn.

Examples of tools which had cracked in grinding were shown and Mr. Palmer claimed that hair lines and checks, especially at right angles to the grinding, could usually be blamed on either the grade of the wheel or the speed of grinding. Deep seated cracks, however, which develop during grinding, can usually be traced to poor heating by the hardener.

Summing up his talk, he stated that a piece of heat treated tool steel has just so much strength, depending on the quality of the steel, its analysis and the treatment which it has received. The reason why so many tools fail prematurely is not necessarily because the steel is weak, but rather because the strains are big. In other words, when the strain within is greater than the strength of the steel, the tool breaks.

After a short discussion, during which a question was asked about the length of time required to properly draw a high speed steel tool at 1100 degrees Fahr., Mr. Palmer produced a series of slides, showing the effect of different lengths of time on the microstructure. He also cautioned against reheating for drawing before the tools had cooled to a temperature below 300 degrees Fahr., for unless this is done, the full benefit of the tempering is not obtained.

A rising vote of thanks was tendered the speaker and the meeting adjourned at 9:30 p. m. *H. E. Handy.*

BUFFALO CHAPTER

The March meeting of the Buffalo Chapter was called to order at 8:30 P. M. by Mr. Blocksidge who was acting as chairman.

J. V. Emmons, metallurgist of the Cleveland Twist Drill Co., was introduced at once as the speaker of the evening.

Mr. Emmons' subject was "High Speed Steels."

Most of the talk was on the analysis and heat treatment of the three most used grades of the high speed steels. The inspection methods for both the small shop and the shop connected with a laboratory were given. A number of lantern slides were shown which gave the structure of the high speed steels in different conditions and also some defects.

An interesting discussion followed.

About forty members and guests attended.

CHICAGO CHAPTER

April 8—Alloy and Carbon Tool Steel in 1926.

Arthur T. Clarage, President, Columbia Tool Steel Co., Chicago Heights, Illinois.

Attendance: 90.

Mr. Clarage's well received talk was a discussion of the factors that are today influencing tool steel for the purpose of assisting selection.

The lengthy and heated discussion which followed had to do chiefly with the matter of good and bad specifications, and the why and wherefore of so-called trade secrets.

Mr. J. Fletcher Harper, National Director, was present and addressed the meeting on the subject of selling the society.

The Coffee Talk was given through the courtesy of the Brunswick-Balke-Collender Co. and Mr. Joseph Spring of the Superior Motors Co., Chicago. The latest developments in recording and reproducing the entire musical scale were clearly outlined by the speaker, emphasis being placed on the transition from the mechanical to the electrical in both instances. The Brunswick Panatrope, a purely electrical reproducing instrument, served to demonstrate the advantages of the new reproduction.

Work on the 1926 Convention and Exposition to be held in Chicago is progressing. All the chairmen for the different convention committees have been appointed and are scheduled to meet April 22 to select their committeemen. *J. A. Comstock.*

CINCINNATI CHAPTER

The March meeting of the Cincinnati Chapter of the A. S. S. T. was held at the Ohio Mechanics Institute on the evening of March 11. There were sixty-two members and guests present.

The membership committee reported that four new members were secured by the Chapter during the last month.

The chairman announced there would be an executive committee meeting on the 22nd of March for the purpose of formulating plans for carrying out the suggestions offered by President Bird and Secretary Eisenman at their meeting with the executive committee on the 8th and invited any members to attend who so desired.

Professor G. M. Enos, University of Cincinnati, was introduced and presented a very interesting and instructive paper on the "Spark Testing of Steels" supplemented with charts and lantern slides as well as by actual testing of a large number of steels before the audience. The tests were so well portrayed that it was no difficult matter for the ordinary inexperienced person to ascertain the different kinds of steel by the various sparks they threw off. This form of testing has found practical application in the industry and is being widely used as a quick and fairly accurate method of steel classification. A great deal of interest was manifested by those present as was proven by the discussion following the paper.

Professor Enos was accorded a rising vote of thanks for his most interesting lecture and the meeting was then adjourned.

The next meeting of this Chapter will be held on April 8. The speaker for this meeting has not been definitely decided upon, however, due notice will be given as to the subject, speaker, etc. *F. L. Martin.*

CLEVELAND CHAPTER

The regular March meeting of Cleveland Chapter was held in the ball-

room of Hotel Winton on March 19, 1926 at 8:00 p. m. At this meeting A. N. Conarroe, Chief Chemist, National Malleable & Steel Castings Co., Melrose Park, Illinois, presented a paper entitled "Heat Treatment of Steel Castings."

Mr. Conarroe having had a great deal of practical experience in heat treating castings was able to explain and emphasize a number of important phases of his subject. His remarks on this occasion were limited to basic open hearth steel castings. The melting and casting were first briefly described, then the heat treatments required were explained. The majority of steel castings are normalized, that is, heated through and well beyond the critical range, then removed from the furnace and allowed to cool in air.

If material is to be subjected to severe stresses, it is desirable to develop a fine-grained structure. This is accomplished by heating as before and quenching in a liquid, then reheating below the critical range to equalize strains and restore ductility. The details of heating the castings in the furnaces were fully covered. The speaker stated that continuous heat-treating furnaces are growing in favor.

Among other subjects discussed by Mr. Conarroe were segregation or ingotism, impurities and foreign inclusions, and the correct procedure in melting. A number of points mentioned were illustrated by excellent photomicrographs. At the conclusion of his talk Mr. Connaroe showed a motion picture film illustrating the heat treatment of anchor chain.

The April meeting of Cleveland Chapter was held at Hotel Winton on Friday evening, April 16, 1926, the speaker being Francis F. Lucas, member of the technical staff of the Bell Telephone Laboratories, New York.

Mr. Lucas presented a paper on "High Power Metallography," and as any who have seen the work of Mr. Lucas can easily believe, this paper was an unusual treat. The exceptionally clear and brilliant photomicrographs which this speaker exhibits are worth going miles to see. The real structure of martensite and of two forms of troostite were revealed by photographs taken at magnifications of 1500 up to 3230.

The speaker explained that it would be easy to take photographs at much higher magnifications, even as high as 50,000 diameters but the results would be worthless because of the fact that with light of given wave-length there is a fixed limit of resolution. Two ways of advancing the art of obtaining better photographs at higher magnifications were mentioned, the first being to make objectives of higher numerical aperture, and the second to use light of different wave-length. Mr. Lucas, in cooperation with one of the manufacturers of optical equipment, has been a pioneer in using both of these methods of obtaining greater resolution at high powers, and so revealing the inner structure of the constituents of metals more clearly than has heretofore been possible.

Mr. Lucas said that objectives of 1.65 N. A. had been produced and showed great promise. He also described the equipment used by him for taking photographs with ultra-violet light. This equipment is very difficult to use successfully, especially because it requires great exactness of focus, and focussing cannot be done in the usual way as when the ordinary equip-

ment is employed. In addition to the fact that with ultra-violet light greater resolution may be obtained, an added advantage is that this light has selective properties which aid in distinguishing between the various constituents.

After viewing the unusually fine slides that were shown, all who were present must have gained not only a more accurate conception of the nature of troostite and other microconstituents of steel, but also must have been impressed with the possibilities of high power metallography. Mr. Lucas has already gone far beyond the average metallographist. He obtains his results by the use of the best and most modern equipment combined with the most advanced technique. He emphasizes the great importance of the proper preparation of samples for this high-power work.

About 150 members and guests attended this meeting. Preceding the meeting the usual steel treaters dinner was served in the hotel dining-room.

A. S. Townsend

DETROIT CHAPTER

The March meeting of the Detroit Chapter of the American Society for Steel Treating was held March 22 on the 15th floor of the General Motors Building. After the dinner, which was well attended as usual, our monthly Coffee Talk was given by J. Henry Wood, manager of the scientific equipment division of the Graybar Electric Co. (The Graybar Electric Co. being a part of the Western Electric Co.). Mr. Wood spoke first of sound waves and illustrated them by a pure tone. He then showed by use of a loud speaker and necessary electric apparatus how the hearing ability of a person could be quantitively determined, by starting with a low frequency just audible and going to high frequencies until sound became inaudible to the listener. The range of frequencies audible is taken as a measure of the hearing capacity. With this knowledge and by the ingenious use of permalloy, which has 100 times the permeability of soft iron, aids to hearing can be made.

Fading of sound waves was illustrated and explained by pure tones. The speaker explained that when radio waves are broadcast in duplicate, one set stays close to the earth's surface and the other is reflected from strata in the air. If these two waves are in phase we have loud reception, and if for some reason they are out of phase, fading results. Using phonograph records and sound filters, records of 350-5000 frequencies were played.

The effect of sound volume was next discussed by Mr. Wood. The lower the volume of sound the higher the pitch and the high volume makes for a low pitch. Overloading a vacuum tube will therefore give a low pitch and is undesirable. In the magnification of sound waves an artificial larynx has been developed for people who have had operations on their trachea, which removes possibility of normal speech. This larynx consists of a diaphragm kept in vibration by breath of the person, but this rate of vibration can be changed at will, and hence with a little practice a person can again talk.

The last sound waves remarked on by Mr. Wood were those of 50-5000 frequencies which the orthophonic victrolas now employ. This is a great extension of frequencies over the older type and results in real reproduction of music heretofore slighted, as for example, the piano.

The meeting then was turned over to T. H. Wickenden of the Inter-

national Nickel Company, who spoke on "Automotive Design and Automotive Steels." As a background Mr. Wickenden presented some interesting data on effects of change of section. If we have a change of section of a 2-inch bar of steel to, say ½ its diameter, and we use 1-inch radius fillet we find a strength of 47,500 pounds per square inch elastic limit at this point. Calling this 100 per cent, for the steel had a strength of 48,000 pounds per square inch elastic limit, we find:

¼ inch radius	44,000 pounds per square inch	92 per cent of total
Square shoulder	23,000 pounds per square inch	39 per cent of total
Notch	19,000 pounds per square inch	40 per cent of total

So that by the careless use of fillets we can easily cut the strength of parts in half.

With these facts in mind and with a view to ascertaining the specific requirements of various parts of an automobile and to determine whether alloy or carbon steel is best, Mr. Wickenden made an analysis of the stresses and factor of safety in the parts. In these days of mass production it is the duty of all to save a few cents per car where possible.

The topics given consideration were the stresses and factors of safety in the front axle and steering knuckle and in the front axle center under maximum vertical load. The material for the axle center, and the advantages of alloy steel for heavy cars, was mentioned. Then Mr. Wickenden worked out the stresses in the steering knuckle spindle when the springs are closed and the axle center when turning a corner. The reaction in the steering knuckle and the possibility of failure of a part through fatigue or excessive stresses in turning a corner were shown. From data presented it seems that if the elastic limit of the steel divided by maximum stress in pounds per square inch as determined in Mr. Wickenden's analysis equals 2 or more there will be no failure, provided at the same time 45 per cent of tensile strength, the endurance limit stress, divided by maximum stress in pounds per square inch is equal to 1.25.

Mr. Wickenden then spoke of the use of oil hardened versus case hardened gears in transmissions. He noted that in a gear of a given size if it pitted when made of an oil hardening steel that very often a carburized gear would run indefinitely with no pitting. Of course, increasing tooth width would again allow use of oil hardening steel. In this connection analysis of 3.5 and 5 per cent nickel steel were given. The tensile properties of 3.5 per cent nickel are but ½ of those of 5 per cent nickel. Mr. Wickenden spoke briefly of an advantage due to cyanide quenching oil hardening gears. The resultant gear wears better than those hardened from an electric furnace. There is, however, a slight loss of Izod value and a greater tendency for warpage. This latter can be cut down by pre-heating.

In calling attention to the rear axle, the demands of rear axle pinions and ring gears were briefly mentioned and the use of at least ½ per cent nickel steel advised instead of straight carbon steel, because less grain growth occurred during carburizing. For these purposes many makers use 3.5 per cent nickel steel.

Axle shafts were considered and charts of the hardening depths of steels

shown. The effects of undercuts and sharp corners present in the splined portion of the shafts was discussed. The necessity of a small section in an axle shaft to assume the load under high stress, acting as a torsion spring, was brought out.

A short discussion followed the paper, and Mr. Wickenden stated that it was best to have metals of different hardness run together. In this regard he knew of factories where 10 points scleroscope difference was kept between ring gear and pinion. Mr. Wickenden was given a rising vote of thanks as the meeting closed.

F. P. Zimmerli.

HARTFORD CHAPTER

The April meeting of the Hartford Chapter took the form of a question meeting in which a large number of questions were printed on the announcement for the meeting and all members came prepared to discuss these questions. These answers appear in the Question Box of this issue of TRANSACTIONS.

LEHIGH VALLEY CHAPTER

On the evening of March 2, an illustrated lecture on the subject, "Metal Cutting Tools," was given by the Lehigh Valley Chapter of the American Society for Steel Treating, by A. H. d'Arcambal, metallurgical engineer of Pratt and Whitney Company.

In his talk, Mr. d'Arcambal gave an instructive resumé of the production of metal cutting tools of quality. He laid stress on three main factors; use of the proper type of material; use of good material and use of correct heat treatment. The possibilities of proper consideration of these factors were presented in the concrete form of a collection of tools returned by customers after having given remarkable service. The variety of tools manufactured by his concern was shown by a second exhibit of modern tools of all descriptions. The result of neglect of any of the factors pointed out as important was shown by a third set in which were examples of the results of all the common manufacturing atrocities, these being mainly poor material, over-heat, under-heat, damage in grinding and incorrect treatment.

High speed steel of the 18 per cent tungsten type was pronounced by Mr. d'Arcambal as having been found far superior to the 14 per cent tungsten material. He laid particular stress on the carbon content, claiming that this was the most important factor in the chemical composition. He pointed out the growing use of high speed as compared to carbon steel, which, of course, forms the second important class of tool material. A third class which demands consideration for use in such tools as taps is that known as alloy tool steel, that is a carbon steel containing some alloy such as chromium. He referred to the high carbon high chromium steel used by a number of tap makers as offering a wide hardening range, but as being very much more difficult to machine. His experience with taps of this material would indicate that its cutting qualities are not superior to those of carbon tool steel. The so-called cobalt high speed steel he considered unsuitable for any tools except those which are finished all over by grinding after hardening. This is because of the soft skin after hardening, which is peculiar to this material.

In comparing carbon and high speed steel as tool materials, Mr. d'Arcambal presented interesting curves which showed why the latter may be run at much greater cutting speeds than possible with carbon steel. These curves showed the comparative hardness of the two materials at temperatures up to 1300 degrees Fahr., estimated as the temperatures attained by high speed tools under heavy duty. When cold, the carbon steel showed a slightly higher hardness than the high speed, but at 600 degrees Fahr., this hardness had dropped to about 75 scleroscope. High speed steel did not fall to this hardness until 1100 degrees Fahr. was reached. It is also interesting to note that number two stellite was no harder at 1100 degrees Fahr. than was the high speed steel.

In order to insure the use of good material, Mr. d'Arcambal recommended purchase of steel by specification rather than by brand. Specifications in the case of Pratt and Whitney include not only chemical, physical and metallurgical requirements, but also hardness limits which place the material within the range of commercial machinability. Much emphasis is placed upon cleanliness of material, this quality being revealed by the hot acid etch. Structure must also be such as has been found by experience to assure grain refinement by heat treatment. Limits of machinability are set in the Brinell scale and all incoming material is checked on hydraulic type Brinell machines.

Great stress was laid upon the importance of correct heat treatment. Wherever possible automatic heat control is recommended. In the case of carbon steel the electric furnaces are used, and for high speed the gas-fired type. Drawing of carbon steel is done in oil and high speed steel in lead. The advantages obtained by drawing after hardening were plainly shown by curves; the two important factors being given as development of factor of safety against cracking and increase in toughness. The fact that drawing reduces the tendency toward cracking is of interest to the tool user since the tendency toward cracking in grinding is much less. Figures from transverse tests of high speed steel showed that the breaking load for drawn specimens was double that of others not so treated. The absolute necessity for cooling from the hardening heat and reheating for the draw was also pointed out. The long draw, say 12 to 24 hours, has not been found beneficial for high speed steel by Pratt and Whitney. Curves were shown which plainly indicated that the scleroscope hardness of tools drawn to 1100 degrees Fahr. was as high as that of the scleroscope after hardening. The drawn tools, of course, showed greater toughness.

For the measurements of hardness of tools, the Rockwell machine is finding favor and for this reason it is worthy to note that a number of tests showed a slight disagreement between Rockwell and scleroscope scales on high speed steel hardened and drawn to 1100 degrees Fahr. Hardened in the neighborhood of 90 scleroscope may be expected to show 5 points higher after drawing while on the Rockwell scale, the hardness after quenching is never reached for any drawing temperature. Attention was called to results of tests on milling cutters made from forged blanks of high speed steel which indicated that on cutters even as small as 4 inches in diameter an improvement in cutting qualities was attained by this treat-

ment. For larger diameters, 6 inches and up, this condition was even more pronounced.

Items of interest to the shop man were also brought out. Mr. d'Arcambal dwelt upon the advantage of the curvex formed milling cutter in which the tooth faces lie in a helix and the backs of the teeth are relieved by a process patented by Pratt and Whitney. The fact that a number of railroads have not found spiral stay-bolt taps superior to straight fluted ones, was also mentioned. In other cases where spiral taps have shown superiority this has been offset by their increased first cost and difficulty in sharpening. Attention was called to the fact that a considerable saving is possible in shops through the use of square-shanked taps rather than those with special shanks such as those of the Beaman and Smith type. Stress was laid upon the merits of ground high speed steel taps. These tools possess superior accuracy and have been accepted as standard by a majority of automobile builders. The importance of extreme care in sharpening tools of all descriptions in such manner as not to blue the corners or edges was emphasized.

Mr. d'Arcambal closed his talk with an offer to answer questions. As a result of participation by other members, a number of items of interest were brought out. B. H. DeLong, of Carpenter Steel Company, made a statement to the effect that the long draw for high speed tools had in several instances to his knowledge produced tools of superior cutting qualities.

MILWAUKEE CHAPTER

The regular meeting of the Milwaukee Chapter was held on March 16 at the Hotel Blatz.

One of the largest attendances of any of our meetings greeted T. H. Wickenden of the International Nickel Co., who gave an interesting talk which was illustrated by charts and graphs on "Automotive Designs and Automotive Parts."

Mr. Wickenden explained the various methods used in computing the stresses on axles, steering knuckles, etc., and how the factor of safety is obtained. The various designs which have stood out well in service conditions and those which had given trouble due to failure were compared and the factor of safety was shown to be much too low on the ones which gave trouble. The advantage of an alloy steel, which has a higher physical property, over carbon steel was shown by substituting the values of the known strength of a heat treated alloy steel in the formulas used in computing the factor of safety on a carbon steel axle which gave trouble due to failure, and it showed a factor of safety high enough to avoid trouble.

This talk was very interesting and the members availed themselves of the opportunity to draw on Mr. Wickenden's wide experience to answer many questions which they wanted help on. The paper was so interesting and so well presented that there have been frequent requests for a copy of the paper and it certainly would be of interest to see it printed in TRANSACTIONS.

N. F. Tisdale.

NEW HAVEN CHAPTER

The regular monthly meeting of the New Haven chapter was held on

April 16 in Bridgeport, where we were the guests of the Heppenstall Forge Company. To say we were royally entertained would be putting it mildly.

The plant inspection started at 2:30 p. m. and up to 5 o'clock we wandered around the various departments watching various forgings being made. Some one made the statement about stopping the hammers on the face of a watch without breaking the crystal, but up to the time of leaving, no one would risk their Ingersoll, so this question is still in doubt.

If you will recall back in January, Mr. Hammond of the Winchester R. A. Co., made a remark about a treated block which was not so hard a few inches below the surface as it was on the face. Well on Friday, one of the large treated die blocks was "busted" and ground to settle this argument. This part of the afternoon's program was so interesting and the crowd so thick around the die block that I was unable to see the results of the tests, so I am still at sea. I could hear from a distance loud talking which I supposed would result in bets but up to the time I left it was another case of "no Ingersoll."

Following the plant inspection, we adjourned to Champ's Farm where we passed the time very enjoyably bowling or playing pool and cards. The various forms of entertainment sharpened the appetitites considerably and at 6:45 p. m. everybody dug into the food with a vengeance.

Immediately after the dinner, the nominating committee composed of Messrs. W. H. Duley, R. G. Hall and A. J. Porter, Jr., made the following nominations for the coming year, viz:

Chairman: C. J. Sauer, Bridgeport.
Vice-Chairman: W. P. Eddy, Jr., New Haven.
Secretary: F. E. Stockwell, New Haven.
Treasurer: W. G. Aurand, Wallingford.
Executive: J. Brooks, East Haven.
R. S. Young, Shelton.
L. W. Burns, Bridgeport.
H. G. Keshran, Waterbury.
R. G. Hall, Wallingford.

The unanimous nomination and election of W. G. Aurand as member of the National Nominating Committee and delegate to the National Convention in Chicago next took place.

About 90 members and guests attended the dinner and a handsome guest prize donated by the Heppenstall Forge Company was won by W. Paul Eddy, Jr.

After the business meeting, George E. Norris, chief metallurgist of the Vanadium Corporation of America, spoke on Vanadium. This very interesting paper was accompanied by slides and following its presentation, a lively discussion took place.

Fifteen towns and cities other than New Haven were represented at this meeting and we were glad to see Messrs. d'Arcambal and Moore present with a delegation from the suburban town of Hartford. More power to you boys and do not forget the June meeting at Savin Rock. It will be a humdinger.

Someone asked if there were any steel salesmen in New England not

present on Friday. Frankly I cannot say but they are always welcome in New Haven.

Many new faces were noticed in the crowd. Membership Committee please take note. We want to see New Haven advance in membership. Give us your support, fellows and get someone signed up. It was worth a year's dues to attend this meeting at Bridgeport.

I did not notice J. H. G. (Alphabet) Williams in our midst. Surely was missed but trust he will be among us next month.

Mr. d'Arcambal gave a very interesting talk of some of the things that are planned to happen in Hartford next month at the Spring Sectional Meeting.

A rising vote of thanks was given to the Heppenstall Forge Company for the wonderful time enjoyed by those present. We understand Messrs. Lindsay, Sauer and Porter were the committee on arrangements. Congratulations to the Committee.

Walter G. Aurand.

PHILADELPHIA CHAPTER

March and April have been busy months for the Philadelphia Chapter, two meetings being scheduled for each month.

The second March meeting, held on the 26th, was unquestionably the best meeting of the year to date, not only in point of attendance, but in the discussions which followed the paper presented by Mr. George Satterthwaite, vice-president, Henry Disston & Sons, Inc., entitled, "The Steel Treater from the Viewpoint of Management." The members of Philadelphia Chapter consider themselves most fortunate in being able to hear a paper of such wide scope so lucidly presented. The paper was discussed by the following members:

A. MacLean, Jr., of Westinghouse Electric & Mfg. Co.
A. J. B. Harris of Ajax Metal Company
W. N. Howley of Tioga Steel & Iron Co.
Richard P. Brown of Brown Instrument Co.
Radclyffe Furness of The Midvale Co.
J. A. Steinmetz, Major, Ordnance Reserve, U. S. A.
Horace C. Knerr, Philadelphia Chapter.

On April 14 the members of the Philadelphia Chapter are to be the guests of the Philadelphia Foundrymen's Association, and on April 23 the regular monthly meeting of Philadelphia Chapter is scheduled, with Mr. Charles F. Hammond, metallurgist, Winchester Repeating Arms Co., and Mr. T. Y. Olsen of Tinius Olsen Testing Machine Co. as the speakers.

A. E. Donovan.

PITTSBURGH CHAPTER

The regular April meeting of the Pittsburgh Chapter was held on the evening of the 1st at the U. S. Bureau of Mines.

A dinner was served in the Mines Restaurant at 6:30 which was well attended. During the dinner a male quartet rendered a very pleasing program.

Promptly at 8 o'clock, Chairman O. B. McMillen called the meeting to order and proceeded with the business of the evening. The various com-

mittee chairmen reported the activities of their respective committees, and following this the annual election of officers and directors of the Pittsburgh Chapter was held. The following were unanimously elected and will be installed into office at the May meeting.

Chairman	W. H. Phillips
Vice-Chairman	J. N. Ludwig, Jr.
Sec'y & Treas.	H. L. Walker

DIRECTORS

W. B. Crowe	W. J. McInerney
J. P. Gill	O. B. McMillen
Prof. S. L. Goodale	A. Roy Pafenbach
Dr. C. M. Johnson	DuRay Smith
Prof. V. N. Krivobok	J. L. Uhler
W. J. Merten	H. R. Wade

Ex-Officio and Honorary
T. D. Lynch

The chairman then introduced the speaker of the evening, A. V. deForest, research engineer of the American Chain Company, Bridgeport, Conn.

Mr. deForest's subject was, "Magnetic Measurements of Stress and Strain," and he demonstrated its application by actual tests with a special apparatus which he had set up.

Mr. deForest said in part:

"The behavior of metals under stress has been studied both extensively and intensively during the past 50 years. The stress-strain diagram is the most customary record of such behavior and may be made to yield very valuable results, but in its ordinary form is not altogether satisfactory. This is due in part to the assumption that the so-called elastic limit is the same in tension as compression. Most testing machines are conveniently operated on a sample under tension or compression, and not for loads changing from one to the other. On annealed material in certain cases the compressive proportional limit may be the same as the limit in tension, but if the material has been strained in the process of manufacture by drawing, rolling, forging or bending below the temperature of recrystallization, the elastic range may be greatly displaced in regard to zero load.

The value of the stress-strain diagram would be increased by plotting a complete cycle from tension to compression as can be done by means of the admirable recording device of Professor Dalby. The proportional limit as ordinarily measured reflects the mechanical treatment of the specimen rather than its probable behavior under repeated load, which is the information usually desired by the engineer. For the latter purpose the elastic range as conceived by Banschinger is more important than the primitive elastic limit as usually measured. Furthermore, the stress-strain curve is not particularly well suited for the determination of the proportional limit, for this point on the diagram is only marked by the transition from a

line substantially straight to a curve of gradually decreasing radius. The more accurate the extensometer and the greater the care in measurement, the lower the apparent load at which permanent deformation begins. Delicate measurements must be made and a plot prepared to determine the proportional limit.

On the other hand, a measurement of stress-magnetic properties has interesting possibilities. The effects of stress on the magnetic permeability of iron and steel has long been known, but measurements with direct current magnetization are slow, require cumbersome apparatus, and their interpretation is difficult owing to a large hysteresis effect between stress and permeability. By making measurements with alternating current, a particular magnetic function can be found in which no hysteresis appears, and any difference between the curve in loading and unloading is an indication of permanent deformation. The measurement of this deformation depends not on the dimensions of the specimen but on a change in the distribution of stress within the material. The sensitivity of the apparatus is under control and no moving parts are attached to the specimen. Furthermore, advantage can be taken of a curious characteristic of stress magnetic curves, namely, that there is a maximum of permeability well within the elastic range.

If all the metal within the magnetizing coil reaches this maximum at the same load, it seems probable that each element of length is carrying its fair share of stress, but if part of the section is under compression while other portions are in tension, in other words if there are internal stresses present, the effect of these stresses will be shown by the sharpness of the peak of maximum permeability.

This effect and the sensitiveness of the magnetic function at zero load were demonstrated by a small machine with which load on a wire could be applied through a spring and recorded as the vertical position of a spot of light projected on the black-board, while the horizontal position of the spot measured the magnetic property under discussion. The stress-magnetic curve was then traced under loads slowly applied and released, and the shape of the curve made evident.''

At the conclusion of this talk many and varied questions were asked which showed that each individual was trying to apply this method of testing to his own problem. Mr. Spooner, of the Westinghouse Electric and Manufacturing Co., gave a brief description of his experience with this type of testing.

The interest in this subject was evidenced by the fact that the length of time of discussion was almost as long as that of the talk, and much real appreciation was induced by Mr. deForest's genialty, clearness of expression and thorough knowledge of the subject.

Harry A. Neeb, Jr.

ROCHESTER CHAPTER

On Monday evening April 12, the Rochester Chapter of the A. S. S. T. held its 68th meeting in the Rochester Athenaeum and Mechanics Institute.

Preceding the meeting the monthly dinner was served to 32 members and friends. After the dinner a very lively business meeting was held. The

slate for election of officers, which is to take place in May, was given to the members, and plans were set for the coming year.

The speaker chosen for the evening was J. V. Emmons, Metallurgist of the Cleveland Twist Drill Co. Mr. Emmons chose as his subject the "Machineability of Steel" on which he is an authority. Mr. Emmons thoroughly explained his subject and went into detail on many of the more important points. A number of good slides were shown by Mr. Emmons. At the conclusion of the talk many members of the Rochester Chapter entered into the general discussion which followed and showed by their many questions with what interest they had followed Mr. Emmons. *C. F. Wattel.*

ROCKFORD CHAPTER

The Rockford Chapter held its monthly meeting on the evening of March 24, at the usual time and place.

After a leisurely dinner, the meeting was called to order by Chairman Hillman. The regular business was soon completed and the meeting was turned over to Mr. Muehlemeyer of the program committee who introduced the distinguished guests of the evening, one of them, R. M. Bird, president, a comparative stranger, and the other, W. H. Eisenman, an old friend. Mr. Bird told of his visits to other chapters and spoke of the steady growth of the A. S. S. T. and the plans for the future of the society. He emphatically showed how each chapter and every individual in each chapter could be of much greater assistance to the national organization by giving suggestions as to what he thought the society needed and by contributing whatever he knew that would be of assistance to others. These suggestions might then make themselves manifest through new data sheets, in the TRANSACTIONS or in some other manner.

Bill dispensed his usual and justly famous line of humor and information. He told of the increasing stability of the society financially and outlined the plans whereby men who are interested in the activities of the A. S. S. T. but who are situated in localities that cannot support a regular chapter of the society will be able to receive the benefits of the society and take part in its activities. Other forward steps hinted at by Mr. Bird were enlarged upon by Mr. Eisenman and their scope is certainly worthy of the society. *R. M. Smith.*

ST. LOUIS CHAPTER

The 57th monthly meeting of the St. Louis Chapter was held on Friday, April 16, 1926, at the American Annex Hotel. A fine spring day brought out a large audience to hear Wirt S. Scott, manager, industrial heating department, Westinghouse Electric & Manufacturing Co., Mansfield, Ohio. The title of Mr. Scott's fine address was "Economies of Electric Furnaces in Metal Working Industry"; this was illustrated by a number of most interesting slides.

The keynote of Mr. Scott's talk was, "do you want quality?" Mr. Scott pointed out the three objectives of industrial progress:

1. Improvement in living and working conditions.
2. Higher quality products.
3. Reduction of labor and resultant reduction in costs.

He believes that electricity in its field will do all these things, and he left the greater part of the members and guests believing the same thing. Mr. Scott's presentation was in general terms, and the broad way it was handled made it an ideal talk before groups who desired real information on this timely subject. He went back twenty years to the time when electric motors were a scarcity, and he was told that business would not pay the extra cost for convenience and efficiency; electric furnaces today have the same difficulty that motors had twenty years ago. Mr. Scott sees electrification in furnaces making rapid strides and among the most progressive manufacturers; the people who know their real costs. The heating medium is each man's problem but his true economy is in results; better results, fewer rejections, better furnace atmosphere, better control, more healthy employees, and better working conditions. To have the side of gas brought up, C. D. Kentnor Jr., gave a very worthy presentation. Everyone thoroughly enjoyed Mr. Scott's fine address and after the discussion, he received a lusty vote of thanks.

The nominating committee, appointed at the last meeting, reported their nominees for the officers and executive committee to be voted upon at the May meeting. The secretary announced the names of six new members.

Alan Jackman.

WASHINGTON–BALTIMORE CHAPTER

Prior to the regular monthly meeting of the Washington-Baltimore Chapter, held on March 19, 1926, a short executive committee session was held to discuss matters of local interest including the membership drive now successfully under way, the development of the Baltimore field to a greater degree, the forthcoming meeting to be held in Baltimore, and also the executive committee's reaction to a bill now pending in Congress concerning licensing of engineers in the District of Columbia. After reaching the necessary decisions in these matters, discussion was entered into with Dr. Zay Jeffries, the speaker of the evening and also national treasurer, of certain national policies, particularly the recent work of the Publication Committee in respect to the nature of material to be incorporated in TRANSACTIONS, and also the extent to which the Society should enter upon heat treatment or other phases of nonferrous practice, either through the medium of the Data Sheets or TRANSACTIONS or at local and general meetings. This discussion carried on through the informal dinner which followed this meeting.

Dr. Jeffries had chosen for his subject "More About Steel." The talk was devoted largely to the phenomena of hardness and hardening in metals, particularly steel, emphasizing the bearing of more recently developed facts upon the explanation for the hardness and hardening of steels propounded by himself and R. S. Archer under the title of the Slip Interference Theory. Mention was first made of the hardening of iron by rather novel methods. The heating of pure iron in conventional equipment to ordinary hardening temperatures, followed by oil or water quenching does not produce an increase in hardness. However, by depositing small globules of iron by means of an electric arc, upon a large mass of cold iron, H. S. Rawdon had obtained a hardness as great as that of eutectoid steel quenched in the usual manner and

tempered to 400 degrees Cent. In another series of researches W. P. Sykes had heated pure iron in an atmosphere of hydrogen to 1450 degrees Cent.; on quenching in water no hardening occurred, but upon quenching in oil, absorption of carbon was so rapid that a cast iron film formed at the surface and melted, producing great hardness and the characteristic structure of white iron. When heating in air to the same temperature, no hardening was observed following either oil or water quenching. The film of scale prevented carburization by the oil. Similar occurrences had been observed when heating high speed steel for quenching in an atmosphere rich in carbon monoxide.

Consideration was next given to the hardening of austenitic manganese steel by thermal treatment and by cold working. It was explained that the development of hardness and magnetism occurring upon long heating in the vicinity of 550 degrees Cent. was due to the transformation of gamma into alpha iron and also the precipitation of carbide. The precipitation of the carbide begins prior to decomposition of the gamma iron to martensite, and on this account the change in hardness occurs at lower temperature, and initially at a higher rate than does the development of magnetism. The higher the carbon content, the more stable is the austenite; hence the excess carbon must be precipitated before the change from gamma to alpha iron occurs. Hardening of practically the same order, namely, from 200 to 500 Brinell may be secured by cold working. In this case precipitation of carbide does not occur, the hardening being due to the formation of alpha iron (martensite) at slip planes. High manganese steel in the austenite form is not in a state of equilibrium, and consequently deformation tends to produce equilibrium. This is generally true of any unstable phase. On the other hand, the austenite of high nickel steels is stable; some hardness develops on cold working, but no alpha iron and consequently no appreciable magnetism. Manganese steel is perhaps unique in being the only common alloy which conforms to the Beilby hypothesis that a slip plane once used cannot be used again due to the hardening at its surfaces by the development of amorphous metal. Other metals do not conform in full to Beilby's conception of the action at slip planes. If it were correct, tungsten would become completely amorphous after being extended to 500 times its original length; actually elongations by working up to 200,000 times have been employed and still the metal was for the most part crystalline. Similarly, iron wire cannot be drawn cold to the point where it will not still show a reduction in area on tensile fracture of 50 to 60 per cent. These metals thus never lose all of their ductility so that the Beilby hypothesis is not generally applicable; if it were, all metal would behave in a manner similar to manganese steel.

Proceeding to a discussion of current views on the hardening of iron, the structure of the iron atom was considered along with the arrangement of the atoms in the alpha and gamma crystalline forms. The art of heat treatment was described as being dependent upon the gamma to alpha change; the reason for the change was not yet, however, understood fully. By alloying and by heat treatment, soft iron could be converted to steel of a hardness twenty times greater than the original metal. In pure iron, failure occurs at low tensile stress because the possibility of atoms sliding past one another on slip

planes is present; under such conditions only a small number of atomic bonds are broken at any given instant and the stress required is small. In hardened steel the structure is so changed that in order to produce rupture a large number of atomic bonds must be broken by direct pull at the same time and consequently the material possesses great strength. The action was compared to the sliding of a piece of iron across the surface of a magnet as against pulling the iron away from the magnet in a direction normal to the contact surface. A similar instance is observed in the difference in force required when tearing a sheet of cloth as against pulling it after it is formed into a roll, by application of axial stress. In all these cases of rupture by low unit loads much movement (elongation) occurs, whereas when rupture is effected in the same material so modified as to require high stress, the movement prior to rupture is relatively small.

Iron may be hardened by refinement of the grain, that is by breaking up the continuity of slip planes so as to necessitate more atomic bonds being broken at any one instant. The extreme condition for such hardening would be grains so small that all the atoms must be pulled apart at once through being unable to slide past each other. Another method of hardening is to dissolve another substance in the iron and form a solid solution. Still another method is by the prevention of slip through the introduction of a harder component to interfere with slip such as occurs with pearlite due to the presence of cementite. When structural features of the constituent being studied can be seen with the aid of the microscope, explanation of the cause of observed properties is generally simple. In the case of martensite, however, the structure is not resolvable by the microscope, and hence many guesses as to the cause of its hardness have resulted. Dr. Jeffries then discussed the data of many recent investigations of the properties of hardened steel and the metallographic constituents which it is found to contain. Among these were included studies of length changes, heat evolution at room temperature and at elevated temperatures, hardness changes under similar conditions, the microscopic segregation of carbon and the occurrence of a higher carbon content in areas austenitic on quenching than in those martensitic after quenching, the location of the thermal transformation points on cooling as affected by the rate of cooling, the changes in electrical resistance due to quenching and tempering, and the variation with composition and tempering treatment changes in the etching characteristics of the constituents of hardened steels. A critical review of these various researches, appraising each at the value which the degree of care in experimentation and interpretation would warrant, has confirmed the speaker and his associates in original conception of the changes occurring during the hardening and tempering operations. These are to the effect that martensite is alpha iron of extremely fine grain size containing carbon in atomic dispersion. Chiefly the grain size, but also to a degree the presence of the "stranger" atoms, is responsible for the hardness of this martensite. The increase in the hardness, the decrease in volume and other phenomena which result upon tempering of this martensite are due to the formation and precipitation of iron carbide in critical size and dispersion, such an occurrence giving rise to additional strength through increased interference

with slip. Further tempering is productive of softening due to increase in size of the iron carbide particles and also in the size of the alpha iron grains. Dr. Jeffries considered the volume changes as not paralleling phase changes quantitatively and therefore dangerous as a basis for conclusions in respect to the extent of such phase change. He described the volume change as resulting from two causes, the creation of voids by removal of atoms from the space lattice when combining to form a compound and also the re-arrangement of interatomic forces and consequent alteration in the atomic spacing. The wide spectral lines obtained from martensite had been originally attributed by the speaker and his associates to fine grain size. It had been suggested, however, that perhaps some grains were under tension while others were under compression and that this would make a difference in atomic spacing which would cause wide lines in the X-ray pattern. Any microscopic segregation of carbon (areas originally austenitic, higher in carbon than those originally martensitic on quenching) might also be productive of this effect due to the different number of carbon atoms in different localities and the resultant effect upon parameters. By changing extremely coarse-grained austenite to fine-grained martensite by quenching and by using a small X-ray beam which impinged upon only three original austenite grains, the speaker's contention had been proven. It was further shown by microscopic evidence that slip in spheroidized steel did not occur by fracture of cementite particles; their only function had been definitely indicated as a reduction in the length of planes of free slip.

The final portion of the talk was devoted to the phenomenon of hardening in carbonless alloys. Dr. Jeffries explained in detail the iron-tungsten and the iron-molybdenum system studied by W. P. Sykes. In the particular alloys in each system which were of greatest interest, consideration of the face-centered lattice did not enter as throughout the range of heat treatment body-centered crystalline solid solution prevailed. The hardening was in these cases due solely to a process similar to that in the hardening of duralumin. This consisted in absorbing a hard compound originally distributed in large masses, by means of high temperature heating, retaining that compound in solid solution by quenching, thus yielding a coarse-grained solid solution, and then by reheating at a lower temperature precipitating in finely divided form the original compound throughout the matrix of the coarse-grained solid solution. No recrystallization or phase-change of the solid solution was involved. Iron-tungsten and iron-molybdenum alloys had been prepared by this means which possessed desirable properties as tools for certain special purposes. In these instances as in the case of duralumin, a minor portion of the hardening resulted from solid solution alone but the major portion was due to slip interference within the solid solution as a result of the precipitation of a hard component within it. Thus one further experimental fact is available to support the contention that carbon in solid solution in iron is not the most important factor in determining the hardness of steels.

In the course of the discussion many interesting subjects were entered upon. It was explained that a material for effective keying of slip planes need not be extremely hard but must always have a resistance to shear in random orientation greater than the resistance of the matrix along the planes of easiest

slip. Much time was devoted to the phenomena of strengthening of metals by under-stressing, and it was pointed out that this was characteristic of all metals, but was most noticeable because most readily obtained in iron-base alloys. In considering the relationship of endurance limit to other properties of metals it was agreed that the rather consistent ratio of endurance limit to tensile strength in steels is quite accidental as there appears to be no good physical reason for such an occurrence. It was pointed out that the amorphous metal hypothesis was still useful as for instance in explaining the properties of metal at grain surfaces. Dealing with the mechanism of slip interference, it was explained that there exists both mechanical obstruction and also energy effects due to the large exposed surface of the disturbing particles. Much discussion was devoted to the proportional limit of metals and the phenomenon of creep. Single crystals have true proportional limits, but the values are generally low; very much lower, indeed, than appears in poly-crystalline commercial metals with present limited methods of testing. The proportional limit of poly-crystalline metal is determined to a great degree by the effect of grain boundaries and in cold-worked metal it is controlled by the properties at planes upon which slip has occurred. In hardened steel the absence of a definite proportional limit is a result of both internal stress and unstable phase conditions. In all metals the amount of elastic movement possible is closely related to the difference between the temperature of the metal when tested and the melting point or recrystallization temperature of the metal.

Jerome Strauss.

WORCESTER CHAPTER

The eighth meeting of the season of the Worcester Chapter was held Thursday evening, April 8th, at the assembly hall of the Worcester Electric Light Company. Members of the American Society of Mechanical Engineers and the American Institute of Electrical Engineers were guests. Nearly 100 were present at the luncheon served at 6:30.

The program for the evening was furnished by the General Electric Company.

The first speaker was Mr. P. P. Alexander, whose topic was "Mixed Gas Welding." Fundamentally mixed gas welding produces a quality of weld free from oxide or nitride inclusions. Therefore, a weld made by this process possesses ductility and physical properties far superior to the present day weld.

Although ductile welds were developed at two separate divisions of the General Electric Company at approximately the same time and independently of each other, the principles employed to make such welds are entirely different. The Schenectady method uses an arc between tungsten electrodes and depends on the heat liberated when atomic hydrogen changes to its molecular state for the welding heat. No arc touches the work and the process is in reality gas welding. The Lynn division procedure, however, is regular arc welding, in which a gaseous envelope of harmless gases is maintained about the work. Both methods produce welds of exceptional quality. Mr. Alexander discussed in detail some of the problems and obstacles which developed in the latter process.

Molecular hydrogen surrounds the arc to exclude oxides and nitrides. A critical voltage—120 volts—must be maintained to produce and maintain the arc. A voltage drop double that of ordinary arc welding occurs in the new process, due to high anode-cathode drops in hydrogen gas. Increased speed is possible because a wider arc may be maintained without injury to the work. Test pieces made of built up metal show an elongation of 30 per cent as against 3 to 5 per cent in regular welds.

The problem of obtaining a satisfactory source of hydrogen gas has been thoroughly studied. Pure hydrogen is a difficult gas to weld in and is not convenient to produce and store. Water-gas—50 per cent H and 50 per cent CO—is more satisfactory and cheaper. Methanol heated to 600 degrees Fahr. breaks up into CO and H. The gaseous mixture is satisfactory and one gallon will produce 240 cubic feet of gas. It is significant that with only 10 per cent of hydrogen and the remainder nitrogen that the quality of the weld is not affected. This makes possible the use of anhydrous ammonia, a fifty-pound cylinder producing 2,250 cubic feet of gas possessing 75 per cent hydrogen and 25 per cent nitrogen. With nitrogen over 80 per cent in the mixture, yet not exceeding 90 per cent, the gases do not burn and the work being welded may be readily seen. Mr. Alexander answered numerous questions regarding the new process.

The second speaker, Mr. Malcolm Thomson, gave an illustrated lecture entitled "Regular Welding."

Special apparatus made by the General Welding Company for welding various parts was shown and described. The increased production obtained by these special installations is very apparent. New fields are opening all the time where welding may be applied and a very complete set of views were shown where electric welding has entered. The substitution of a weld for a rivet has been accomplished in many varied industries.

Mr. T. Davis, with the aid of a special projector, demonstrated arc welding in a manner that the audience could actually see on the screen what takes place in the process, the fused and flowing metal, the crater formed and the melting away of the rod. He likewise demonstrated the process, using a carbon electrode.

The last feature of the evening was a four-reel motion picture entitled "The Yoke of the Past." This film showed the various stages of advancement made in farming, beginning with the crude hand or ox-drawn plow, through the treadmill period for farm power, the steam engine, gasoline engine and, finally, the electric age on the farm. The numerous and varied applications of electricity in the house, barn, fields and woods show the extent to which electricity has entered into farm life to lighten labor and improve conditions.

E. D. Clark.

PATENT REVIEWS *(Continued from page 816)*

hardening temperature. The liberation of the cyanide under pressure in the cylinder increases the hardening or carburizing action. The temperature of the reaction may be controlled by the introduction of compressed air from the tank 11 and when the reaction has proceeded to the required point, the poisonous gases may be discharged by opening the valve 6, shutting off the flow of chlorine and forcing compressed air through the cylinder and compound 2 to drive out the poisonous gases.

NEW MEMBERS OF THE SOCIETY

EXPLANATION OF ABBREVIATIONS. M represents Member; A represents Associate Member; S represents Sustaining Member; J represents Junior Member; and Sub represents Subscribing Member. The figure following the letter shows the month in which the membership became effective.

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MCGILL METAL CO., (S-1), F. R. Schubert, vice-president; *mail* 915 Lafayette St., Valparaiso, Ind.

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MIEROW, A. W., (A-3), salesman, Columbia Tool Steel Co.; *mail* 137 Sycamore St., Milwaukee.

MILLER, F. J., (M-3), labor assistant, Ingersoll-Rand Co.; *mail* 15 Henderson St., Phillipsburg, N. J.

MILLER HARRY, (M-4), foreman of machine shops, Roller-Smith Co., Bethlehem, Pa.

MORTON, W. W., (M-4), owner, W. W. Morton Co., 131 Federal St., Camden, N. J.

MUECKE, G. A., (M-3), carbonizing foreman, International Harvester Co.; *mail* Box 108, RT 4, West Allis, Wis.

MULL, J. W., Jr., (S-11), general manager, J. W. Mull, Jr. Co., 412 Board of Trade Bldg., Indianapolis.

MULVANEY, F. B., (M-3), United Alloy Steel Corp., 1411 Ford Bldg., Detroit.

(New Member List to be Continued in June Issue)

Employment Service Bureau

This bureau is for all members of the Society. Want ads will be printed at the following rates: minimum of 30 words $0.50; each additional word $0.02.

This service is also for employers, whether members of the Society or not. Rates for this service are as follows: minimum of 50 words $1.00; each additional word $0.02. Fee must accompany copy.

Address answers care of AMERICAN SOCIETY FOR STEEL TREATING, 4600 Prospect Ave., Cleveland, unless otherwise stated.

POSITIONS WANTED

METALLURGICAL ENGINEER. Graduate Lehigh University, age 25. Four years practical experience in iron and steel foundries. At present second assistant to the production manager of a large corporation but desires change of position either in capacity of metallurgist or sales work in the east or middle west. Salary $160-175 per month. Address 5-5.

PRACTICAL HARDENER. Blacksmithing and hardening of dies and tools of any kind, high speed or carbon steel. Can make furnaces and repair same, if necessary. Address 5-10.

FORGE SHOP FOREMAN, practical and competent, desires position. Has had 22 years' experience in all kinds of hammer forging, hardening, heat treating and tool maintenance. At present employed, and reasons for change are very good. Will furnish very good references. Address 5-15.

OPEN-HEARTH SUPERINTENDENT with metallurgical experience in both acid and basic steels wishes to connect with organization desiring someone that knows the specialty steel manufacture. Can furnish references. Address 4-10.

METALLURGIST-SUPERINTENDENT with 16 years' experience in metallurgical work and manufacturing desires a change. Age, 41. Cornell graduate. Last 8 years with ball-bearing manufacturer. Looking for a position of trust and responsibility. Address 4-15.

POSITION WANTED with progressive firm as foreman of its steel treating department by capable man whose experience covers both heavy work and fine tools and who has held executive positions for the past ten years. Age, 39. Married. Address 4-20.

INSTRUMENT MAN is desirous of changing position. Has had 5 years' practical experience in pyrometer and physical testing laboratories and some chemical analysis. Also experienced in the use and repair of hardness testing machines, pressure gauges and oxygen-acetylene equipment. Prefer permanent position with future. Address 4-5.

POSITIONS OPEN

Technical graduate for Drop Forging Plant in the Pittsburgh District. Very good opening for a young man between 24 and 35 with a knowledge of metallurgy. Must be able to read blue prints, technical training is desired, and should have some experience in steel mills or forging plants. Very good opportunity for advancement for a man who is not afraid of work and is a pusher and organizer. Write Drawer C, Coraopolis, Pa., and give full description of your training, experience and salary desired.

MECHANICAL ENGINEER. A Drop Forging Plant in the Pittsburgh District desires to engage the services of a mechanical engineer or draftsman who has had experience in the drop forging or steel industries. Position involves plant layouts, structural work, die design, development of products, etc. A technically trained man preferred but not essential. Must be between 25 and 35 years of age, a hard worker and have some experience in the above lines. Write Drawer C, Coraopolis, Pa., giving full particulars, age, experience and starting salary.

WANTED: Man who has had some experience on cold heading tools. Up to date shop. Ideal working conditions. Give experience, salary, and when available. Location—Chicago, Ill. Address 4-30.

WANTED: Young man with technical training and one or two years' practical experience in machine shop, steel mill or laboratory, to develop into sales work on special and alloy steels.

Answer in full, giving age, nationality, religion, marital state, education and experience. State salary desired. Address 5-20.

YOUNG MAN WANTED for sales work in Boston vicinity with dealer in furnace and allied equipment. Some engineering training preferred. Address 5-25.

SALESMAN—Technical man preferred with experience in carburizing and heat treating practice. Position requires traveling. Previous sales experience preferred but not essential. State experience, age, salary expected. Address 5-30.

The Clearing House

For the Sale of Used Equipment

		1 time	2 times	3 times	4 times
Rates per Insertion	1 inch[1] ...	$ 4.50	$ 4.25	$ 4.20	$ 4.00
	2 inch ...	8.50	8.00	7.75	7.50
	3 inch ...	12.00	11.50	11.25	11.00

[1]There are 12 lines to an inch. A charge of 40 cents per line will be made for extra lines.

FOR SALE

FOR SALE: Exceptional Leeds & Northrup Furnaces. Guaranteed Brand New. Will sell at very great sacrifice. L & N "Hump" Heat Treating Furnace—1 No. 8058 Furnace, inside dimensions, 8½ inches in diameter and 22 inches deep. One No. 8551—F—8 Recorder. L & N Drawing Furnace—1 No. 9262—24 furnace, inside dimensions, 12 inches in diameter and 24 inches deep. One No. 8970 Control Panel. One No. 8571—D—D—39 Controller. These furnaces were intended to through-harden automobile crankshafts made of ball-bearing steel which have been eliminated in the design and which has made the furnaces unnecessary. They were used only in a test, for a few hours. Address 3-40.

WANTED

WANTED—Used Shore Scleroscope in good condition. Price must be right. Address 4-25.

Items of Interest

THE Brown Instrument Company, Philadelphia, announces a new model Brown Recording Pyrometers which put heat treating temperatures down in "black and white" and have many other features for the convenience and better service for users. A booklet which has been made quick-reading for busy men illustrates the importance of this "black and white" idea and of the Brown Pyrometer improvements in an interesting manner. Booklet and information furnished upon request.

F. S. Blackall, Jr., of the Providence Chapter has been elected to the board of directors of the Taft-Pierce Manufacturing Company of Woonsocket, R. I. Mr. Blackall is also assistant manager and assistant secretary of the company.

Dr. Ing. G. Wazau of Kristiania (Oslo), Norway, has available circulars describing his "Calibrating Testers" and "Ringtesters" used for checking universal and Brinell testing machines.

Harry Hardwicke was unanimously elected a vice president of the Atlas Steel Corporation of Dunkirk, New York, at a meeting of the board of directors held March 30. He is also district manager of the above company.

J. A. Succop is again with the Heppenstall Forge and Knife Company of Pittsburgh in charge of their research work.

William A. Edwards has undertaken some special work for the Ludlum Steel Company of Watervliet, N. Y., and in the development of their business in the oil fields with offices at 710 Leeland Avenue, Houston, Texas. He was formerly manager of the Chicago District for the above company.

Hardite Metals, Inc. has appointed Mr. C. Q. Swenson, Metallurgical Engineer, as their Western sales representative. Mr. Swenson was formerly associated with A. O. Blaich Company of Detroit.

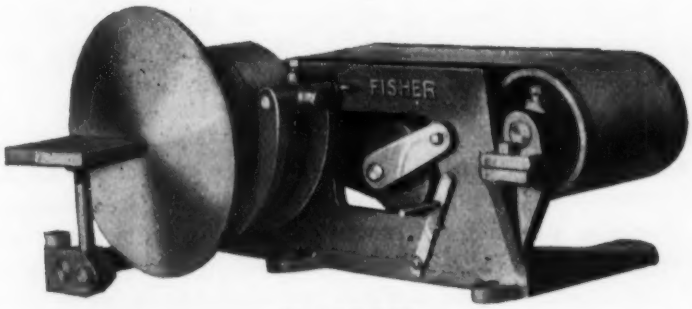
J. W. Barnett, member A. S. S. T., formerly connected with the Philadelphia office of the Crucible Steel Company of America and for the past 15 months with the Baltimore office, has recently received deserved recognition and has been promoted to manager of the Baltimore District.

Norman Conn, formerly metallurgist with the Minneapolis Steel and Machinery Company and past chairman of the North West chapter of the Society has accepted a position with the Vincent Steel Process Company of Detroit.

Hammond & Littell, patent attorneys, announce their change of address from 110 East 42nd Street to 475 Fifth Avenue, New York City. Mr. Littell is a member of the Society and contributes the "Patent Reviews" appearing in each issue of TRANSACTIONS.

(*Continued on Page 36 Adv. Sec.*)

Metallographic Belt & Disc Grinder



No. 12-255

For the rapid grinding or surfacing of metal specimens

ROUGH GRINDING. The specimen is held against the flat steel top over which the grinding belt runs. The coarse grinding is done in straight parallel lines; each finer grinding is made with the lines at right angles to those produced by the previous grinding.

FINE GRINDING. The grinding is finished on Metallographic Emery Paper attached to the flat steel disc on the side of the machine.

Price $60.00

Fully described in the Fisher Catalogue, Page 438

FISHER SCIENTIFIC COMPANY

LABORATORY SUPPLIES

PITTSBURGH, PA. U.S.A.

(Formerly Scientific Materials Company)

E. P. Gaffney, formerly district manager for Wheelock, Lovejoy & Co., New York, has resigned to accept a position with the Crucible Steel Company of America to take charge of their alloy and machine steel department.

A. S. Hummel, formerly with Taylor Wharton Iron and Steel and a member of the Lehigh Valley chapter, has accepted a position with the Southern Manganese Steel Company of St. Louis.

Franz Roessler, chairman of the board of directors of The Roessler and Hasslacher Chemical Company, died on March 24. He and the late Jacob Hasslacher were founders of that organization in 1885.

The Brown Instrument Company of Philadelphia has published an Instruction Book for the "Installation and Care of Thermo-Electric Pyrometers." The theory of thermo-electric pyrometry, the installation of pyrometers, and checking pyrometer installations are explained and illustrated in this 76-page booklet. This is supplemented by maintaining service men throughout the country whose services are available to users by request and by subscription to the Brown Periodic Maintenance Service. Complete information will be furnished upon request.

Another booklet published by The Brown Instrument Company is entitled "Brown Resistance Thermometers." These instruments are for measuring temperatures from —300 degrees to +1000 degrees Fahr. indicating, recording and controlling. This is well illustrated and is available to those interested.

The Bristol Company, Waterbury, Conn., announces that a new Bristol Pyrometer Controller Model 479 has been developed which is the result of four years experimental work and also trial under actual operating conditions in the field. It is said that it includes the recent improvements found in other types of Bristol's Pyrometric Equipment and also incorporates many additional and exclusive features. Literature and information pertaining to this new automatic temperature control may be obtained by those interested.

F. B. Hufnagel was elected president of the Crucible Steel Company of America at a directors meeting held on April 23, to fill the vacancy caused by the resignation of E. C. Collins. Mr. Hufnagel has served in the capacity of vice-president of this company for the past six years. A. T. Galbraith, formerly sales manager, was elected vice-president. Mr. Hufnagel has been active in the steel industry in the Pittsburgh district for thirty years. He resides at Edgeworth, Pa.

Henry Disston & Sons, Inc., of Philadelphia, manufacturers of saws, tools, and steel, announce the appointment of H. A. Baxter as manager of their steel sales department, succeeding Charles T. Evans, who has retired on account of poor health after many years as manager of the department. Mr. Baxter has been general manager of sales for the Tacony Steel Co. and the Penn Seaboard Steel Corp., of Philadelphia, for the last three years. Prior to that he was associated with the H. H. Franklin Automobile Co., the Midvale Steel Co., and the Tacony Ordnance Corp. He is a graduate of the University of Michigan and is a member of a number of engineering and scientific societies, including the Iron and Steel Institute of London.

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IN THEIR FINISHED PRODUCT

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TOOL STEEL
MAGNET STEEL
SPECIAL ANALYSIS STEEL

SHEETS
BARS

∞

SIMONDS STEEL MILLS
LOCKPORT, NEW YORK

THE QUESTION BOX—Continued

the quality is maintained. The small users can obtain valuable information from steel salesmen or can obtain the services of consulting metallurgists. All can obtain useful information by attending meetings of the A. S. S. T.

QUESTION. Why does a machined surface become harder in quenching than a polished surface?

ANSWER. The machined surface offers many small fins to the quenching medium and provides a larger surface for taking away the heat at a faster rate than in the case of a polished surface. The machined surface also has the ability to throw off scale more readily than polished surfaces and thus to a greater extent prevents the formation of vapor pockets.

QUESTION. Why do manufacturers of tools who use the most approved methods of heat treating high speed steel harden their own lathe tools in a forge fire?

ANSWER. Lathe tools are ground all over after hardening and can thus be subjected to a dripping heat which would be disastrous to a tool such as a tap. These high heats give better life to lathe tools, but would soon ruin high speed furnaces, although readily obtained in an open forge.

Report submitted by R. W. Woodward.

DO YOU KNOW?

There is a world of valuable information contained in the A. S. S. T. Handbook and so in an endeavor to emphasize this point, questions will be printed on this page each month. The number and page of the data sheet containing the answer will be given also.

If you are not sure of the answer to all of these queries or even if you are, why not verify it by looking in your handbook. There you will find the answers to these important questions and also you will observe many other important facts that probably you did not realize were in your own A. S. S. T. Handbook.

1. *What is the boiling point of lead?*
   ANSWER: A. S. S. T. Handbook, page A-6a.
2. *What method is used to determine the weight of odd-sized steel bars?*
   ANSWER: A. S. S. T. Handbook, page A-15.
3. *At what temperature does the formation of Gamma iron take place?*
   ANSWER: A. S. S. T. Handbook, page A-25.
4. *When testing steel to determine its corrosion resisting properties, what tests are usually made?*
   ANSWER: A. S. S. T. Handbook, page A-50.
5. *What is the approximate chemical analysis of spiegeleisen?*
   ANSWER: A. S. S. T. Handbook, page A-76.
6. *When adding ferro silicon to the furnace, what is the silicon loss?*
   ANSWER: A. S. S. T. Handbook, page A-78.
7. *Does grinder's scorch interfere with the stainless qualities of stainless steel?*
   ANSWER: A. S. S. T. Handbook, page D-5.
8. *What alloying elements are usually used in finishing steels?*
   ANSWER: A. S. S. T. Handbook, page N-9.
9. *What metals are used for thermocouples?*
   ANSWER: A. S. S. T. Handbook, page S-5.
10. *In photomicrography, what solution is suitable for the fixing bath?*
    ANSWER: A. S. S. T. Handbook, page T-33.
11. *What is the sulphur content of screw stock?*
    ANSWER: A. S. S. T. Handbook, page U-3.
12. *What is the formula used for calculating the Brinell hardness number?*
    ANSWER: A. S. S. T. Handbook, page V-1.